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ERG

Draft Final Report

TECHNOLOGICAL FEASIBILITY STUDY AND COST AND IMPACT ANALYSIS OF THE DRAFT CRYSTALLINE SILICA STANDARD FOR CONSTRUCTION

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SECTION ONE

INTRODUCTION

The Occupational Safety and Health Administration (OSHA) is considering a revision to the existing Permissible Exposure Limit (PEL) for respirable silica in construction work. This analysis examines the technological and economic feasibility of reducing the PEL. The analysis considers two alternatives to the current construction PEL, namely 50 and 75 micrograms per cubic meter ($\mu g/m^3$). The analysis also looks at the costs of rigorous compliance with the existing PEL.

The following sections profile the construction industry and present technological feasibility reports for construction task categories with the potential for exposure to respirable crystalline silica. Section 2 presents a profile of the construction industry, including employment data and the number of employees considered to be potentially at risk of silica exposures. The technological feasibility reports in Section 3 include a process description, exposure profile, and technological feasibility analysis for each task category. Section 4 presents the potential costs of incremental silica control efforts in these tasks. Finally, Section 5 analyses the potential financial impacts on construction industry establishments.

1.1 DRAFT REGULATION

OSHA's draft regulation will present a reduced PEL (to be determined) and several programmatic requirements for affected workplaces. As mentioned above, this analysis considers revised PELs of 50 and 75 $\mu g/m^3$. Based on the draft standard provided by OSHA, ERG evaluated compliance with five program elements: exposure assessment, health screening and surveillance, information and training programs, regulated areas, and hygiene requirements.

The draft regulation also introduces a table of regulatory requirements that specify acceptable silica dust–reducing controls for a number of dust-generating construction activities. The regulation's Table 1 presents acceptable engineering controls and respiratory protection for achieving compliance with the regulation. Employers who satisfy these requirements are deemed in compliance with the standard.

SECTION TWO
CONSTRUCTION INDUSTRY PROFILE

The construction industry is an integral part of the nation's economy, counting for almost 6 percent of total employment. Establishments in this industry are involved in a wide variety of activities, from land development and subdivision to homebuilding, construction of nonresidential buildings and other structures, heavy construction work (including roadways and bridges), and a myriad of special trades such as plumbing, roofing, electrical, excavation, and demolition work.

Among these activities, many tasks expose construction workers to respirable silica. These include impact drilling, earth drilling, rock crushing, operation of heavy equipment, use of stationary saws for masonry cutting, drywall finishing, grinding and tuck-pointing, milling, and hole drilling with handheld equipment.

The following sections present profile data for construction industries. Section 2.1 describes the NAICS structure of the construction industry and presents establishment and employment information. The characteristics of construction investment are discussed in Section 2.2 and the selection of construction activities for analysis is presented in Section 2.3.

2.1 CONSTRUCTION INDUSTRIES IN NAICS

Construction industries are classified in the following four-digit North American Industry Classification System (NAICS) codes:

2331 Land Subdivision and Land Development
2332 Residential Building Construction
2333 Nonresidential Building Construction
2341 Highway, Street, Bridge, and Tunnel Construction
2349 Other Heavy Construction
2351 Plumbing, Heating, and Air Conditioning Contractors
2352 Painting and Wall Covering Contractors
2353 Electrical Contractors
2354 Masonry, Drywall, Insulation, Tile Contractors
2355 Carpentry and Floor Contractors
2356 Roofing, Siding, and Sheet Metal Contractors
2357 Concrete Contractors

2358 Water Well Drilling Contractors
2359 Other Special Trade Contractors

Table 2-1 presents a summary of industry data from the 2000 County Business Patterns (CBP) for facilities classified in the above NAICS (U.S. Bureau of the Census, 2001).

Of the 6.5 million employees in the construction industry, ERG estimates that 2.6 million (39 percent) are potentially at risk for respirable crystalline silica exposure. ERG calculated the number of at-risk employees using the Bureau of Labor Statistics' (BLS's) 2000 *Occupational Employment Survey* (OES) and reconciling it with the CBP data presented above (U.S. Department of Labor, 2001). For each SIC code, ERG extracted the number of employees for each of 17 selected OES occupations involving tasks with potential silica exposure. Since OES data are available only on a three-digit SIC code basis, ERG also translated the corresponding four-digit NAICS code for each SIC code.

In using both OES and CBP data, it was necessary to adjust the OES data to reflect differences in the employment totals between the two sources. ERG benchmarked the OES employment totals to the CBP data by calculating the ratio of employment totals between the two sources. (This step was taken after the NAICS-SIC correspondence was developed.) The OES data were then multiplied by the ratio of the two sources. Table 2-2 presents the number of employees considered to be potentially exposed to silica for each of the OES occupational codes considered. As the table shows, ERG calculated that 2.6 million construction employees are at risk for potential silica exposures.

2.2 CHARACTERISTICS OF CONSTRUCTION INVESTMENT

According to U.S. Census Bureau statistics, the value of construction put in place in 2001 was $842.5 billion. As Table 2-3 shows, residential building construction accounted for $393.4 billion, or 46.7 percent of the total. Nonresidential building construction accounted for another $293.3 billion (34.8 percent). The remainder of construction investment is divided between highway and street construction ($54.0 billion) and other nonbuilding construction projects ($50.6 billion).

Table 2-1. Construction Industries—2000

NAICS Code Industry	No. of Establishments	Total No. of Employees	Establishments With <20 Employees	Establishments With 20–99 Employees	Establishments With >99 Employees
2331:Land subdivision & land development	13,111	77,885	12,434 (2%)	600 (1%)	77 (1%)
2332: Residential building construction	159,550	781,012	153,822 (24%)	5,286 (9%)	442 (6%)
2333: Nonresidential building construction	43,693	746,016	35,623 (6%)	6,997 (12%)	1,073 (14%)
2341: Highway, street, bridge, & tunnel construction	11,795	304,936	8,405 (1%)	2,730 (5%)	660 (9%)
2349: Other heavy construction	27,721	596,051	21,968 (3%)	4,907 (8%)	846 (11%)
2351: Plumbing, heating, & air conditioning contractors	90,487	897,912	80,755 (13%)	8,784 (15%)	948 (13%)
2352: Painting & wall covering contractors	40,973	221,787	38,908 (6%)	1,942 (3%)	123 (2%)
2353: Electrical contractors	66,802	815,056	58,296 (9%)	7,393 (13%)	1,113 (15%)
2354: Masonry, drywall, insulation, tile contractors	53,625	564,994	47,384 (7%)	5,494 (9%)	747 (10%)
2355: Carpentry & floor contractors	58,525	347,303	55,550 (9%)	2,677 (5%)	298 (4%)
2356: Roofing, siding, & sheet metal contractors	30,966	260,774	27,939 (4%)	2,789 (5%)	238 (3%)
2357: Concrete contractors	30,238	292,569	27,133 (4%)	2,801 (5%)	304 (4%)
2358: Water well drilling contractors	3,797	21,590	3,621 (1%)	170 (0%)	6 (0%)
2359: Other special trade contractors	78,307	644,915	71,507 (11%)	6,147 (10%)	653 (9%)
Total	**709,590**	**6,572,800**	**643,345**	**58,717**	**7,528**

Source: U.S. Bureau of the Census, 2001.

Table 2-2. Number of Construction Employees at Risk—2000		
Occupational Code	**Occupational Title**	**Total Employment**
47-1011	First-Line Supervisors/Managers of Construction Trades and Extraction Workers	364,137
47-2021	Brickmasons and Blockmasons	97,839
47-2022	Stonemasons	8,112
47-2031	Carpenters	686,850
47-2051	Cement Masons and Concrete Finishers	141,654
47-2061	Construction Laborers	682,085
47-2071	Paving, Surfacing, and Tamping Equipment Operators	37,685
47-2073	Operating Engineers and Other Construction Equipment Operators	195,126
47-2081	Drywall and Ceiling Tile Installers	113,001
47-2082	Tapers	34,778
47-3011	Helpers—Brickmasons, Blockmasons, Stonemasons, and Tile and Marble Setters	55,642
47-3012	Helpers—Carpenters	91,780
47-5021	Earth Drillers, Except Oil and Gas	9,641
47-5031	Explosives Workers, Ordnance Handling Experts, and Blasters	1,044
47-5081	Helpers—Extraction Workers	5,199
51-9021	Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	939
53-7032	Excavating and Loading Machine and Dragline Operators	40,584
Total		**2,566,096**
Source: U.S. Bureau of the Census, 2001, and U.S. Department of Labor, 2001.		

Table 2-3

Value of Construction Put in Place, 1997 and 2001
($millions)

Type of Construction	1997			2001			5-Year Growth	Average Annual Growth
	Private	Public	Total	Private	Public	Total		
Residential buildings	$289,014	$5,229	$294,243	$388,705	$4,751	$393,456	33.7%	6.7%
Single unit	$175,179	NA	$175,179	$249,086	NA	$249,086	42.2%	8.4%
Multiple units	$22,883	NA	$22,883	$30,686	NA	$30,686	34.1%	6.8%
Improvements	$90,951	NA	$90,951	$108,933	NA	$108,933	19.8%	4.0%
Nonresidential buildings	$173,875	$64,561	$238,436	$201,094	$92,216	$293,310	23.0%	4.6%
Farm nonresidential	$3,815	NA	$3,815	$6,134	NA	$6,134	60.8%	12.2%
Public utilities	$33,638	NA	$33,638	$51,114	NA	$51,114	52.0%	10.4%
Highwways and streets	NA	$42,602	$42,602	NA	$54,026	$54,026	26.8%	5.4%
All other	$2,392	$38,303	$40,695	$2,983	$41,516	$44,499	9.3%	1.9%
Totals	$502,734	$150,695	$653,429	$650,030	$192,509	$842,539	28.9%	5.8%

Source: U.S. Bureau of the Census. 2002, Value of Construction Put in Place: October 2002. December.

Between 1997 and 2001, construction investment grew at an average annual rate of 5.8 percent, with growth rates for individual categories ranging from 12.2 percent for farm nonresidential construction to 1.9 percent for the residual "all other" category. In the residential building category, single-unit construction investment grew at an annual rate of 8.4 percent, while investment in improvements grew at 4.0 percent. Public utility investment also grew rapidly over the 1997–2001 period, with an annual growth rate of 10.4 percent.

Construction investment is disaggregated by whether it is privately or publicly financed. Currently, private construction makes up 77.2 percent of total investment ($650.0 billion) and is dominated by building construction ($589.8 billion). Public construction investment by the Federal government and by state and local governments totaled $192.5 billion, of which nonresidential building construction and street and highway construction accounted for 47.9 and 28.1 percent, respectively, of the total.

Data from the 1997 Economic Census (Table 2-4) show how construction investment is divided among the various construction industries. In 1997, building contractors (NAICS 223) accounted for 45 percent of total construction investment ($381.6 billion), heavy construction contractors (NAICS 234) accounted for 15 percent ($127.8 billion), and the remaining 40 percent ($336.1 billion) was divided among the various special trade contractors (NAICS 235). Among this latter group, masonry, drywall, insulation, and tile contractors (NAICS 2354) and concrete contractors (NAICS 2357) were responsible for $38.1 billion and $25.8 billion, respectively, in total construction investment. These industries are particularly impacted by the prospective silica regulation.

Table 2-4 also shows the distribution of construction investment by type of contractor. These data show that building contractors specialize heavily in building construction projects. Nonbuilding construction investments account for just 1.6 percent of the gross value of construction work by these contractors. Similarly, heavy construction contractors do little building construction work. Nonbuilding construction accounts for 95.2 percent of the gross value of construction work undertaken by this industry. Among special trade contractors, building construction represents 86.7 percent of gross value of construction investments. The data show that masonry, drywall, insulation, and tile contractors are even more specialized in building construction (95.8 percent of gross construction investment), while concrete

Table 2-4

Total Value of Construction Work, by Type of Construction, 1997

NAICS/Industry	Total Value Construction Work [a]	Value of Building Construction Work		Value of Nonbuilding Construction Work		Value of Other Construction Work, nsk	
233 Building, developing, and general contracting	$381,641,600	$371,426,049	97.3%	$5,970,952	1.6%	$4,244,630	1.1%
234 Heavy construction	$127,841,600	$5,218,782	4.1%	$121,763,483	95.2%	$859,210	0.7%
235 Special trade contractors	$336,060,352	$291,247,504	86.7%	$41,261,774	12.3%	$3,550,982	1.1%
2354 Masonry, drywall, insulation, & tile contactors	$38,092,892	$36,507,739	95.8%	$1,347,529	3.5%	$246,685	0.6%
2357 Concrete contractors	$25,848,848	$17,221,866	66.6%	$8,292,613	32.1%	$334,369	1.3%
– All other special trade contractors	$272,118,612	$237,517,899	87.3%	$31,621,632	11.6%	$2,969,928	1.1%
23 All construction contractors	$845,543,552	$667,892,335	79.0%	$168,996,209	20.0%	$8,654,822	1.0%

[a] Includes construction work contracted out to others. Establishments with payroll only.
nsk: not specified by kind.
Source: U.S. Bureau of the Census, 1997 Economic Census: Construction Industry Summary. January, 2000.

contractors' work is more evenly divided, with nonbuilding projects accounting for 32.1 percent of gross construction investment.

2.3 SELECTION OF CONSTRUCTION ACTIVITIES FOR ANALYSIS

The technological feasibility analysis focuses on a selection of construction activities that generate the most problematic respirable silica exposures among construction workers. To select workers and their activities, ERG worked with OSHA to review historical data from the OSHA Integrated Management Information System (IMIS) and the National Institute for Occupational Safety and Health (NIOSH) on recorded samples of construction worker exposures. In addition, the industrial hygiene literature was reviewed across the range of construction activities. OSHA directed ERG to note dusty operations where the silica sand was most likely to be fractured or abraded by work operations. Such physical processes are believed likely to cause the silica exposures that pose the greatest risk of silicosis for workers.

With these selections, ERG has endeavored to address the pertinent problems of technological and economic feasibility of lowering the PEL for construction workers. Other exposure circumstances are expected to be less difficult to resolve than those addressed here.

2.4 ABRASIVE BLASTING

The draft silica standard includes specific requirements for construction workers who perform abrasive blasting. Occupational employment data collected by the BLS, however, are not sufficiently disaggregated to provide statistics of employees who perform blasting tasks. Some of these workers are, presumably, subsumed in the broad occupational classification "painters, construction and maintenance." Using data from the 1997 Economic Census, ERG estimated the number of blasters based on the ratios of construction investment per worker by painting contractors for construction work on bridges, tunnels and related highways; ships; and other nonbuilding construction where abrasive blasting is most likely to occur. ERG used the same method to extrapolate the number of workers who might work as abrasive blasters for "sand blasting contractors, building exteriors." In all, ERG estimated that 17,040 construction workers might perform abrasive blasting. Of these, ERG projected that 8,521 might work for painting contractors (NAICS 2352), while the remaining 3,199 are engaged by sand blasting contractors (NAICS 2359) for work on building exteriors. Assuming an average of 10 blasters per establishment, ERG estimated 852 and 320 blasting establishments in these NAICS classifications, respectively.

2.5 REFERENCES

U.S. Bureau of the Census. 2002. Value of construction put in place: October 2002. December.

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SECTION THREE

EXPOSURE PROFILES AND TECHNOLOGICAL FEASIBILITY ANALYSES

The following sections describe the evidence on construction worker exposures to respirable silica, the current use of controls to prevent exposures, and the potential for and feasibility of using additional controls.

Section 3.1 provides an overview of the exposure data for each of the construction activities. The exposure tables presented in that section are referenced throughout the later exposure profile and feasibility discussions.

The construction activities are described in listed in alphabetical order, as follows:

3.2 Drywall finishers
3.3 Earth drillers
3.4 Grinders and tuck-pointers
3.5 Heavy construction equipment operators
3.6 Hole drillers using hand-held tools
3.7 Impact drillers
3.8 Masonry cutters using portable saws
3.9 Masonry cutters using stationary saws
3.10 Millers using portable or mobile machines
3.11 Rock crushers
3.12 Underground (tunnel) construction workers

3.1 EXPOSURE PROFILES FOR CONSTRUCTION WORKERS

In order to develop the exposure profiles for these construction job categories, ERG compiled all identified industrial hygiene literature with sample information and also conducted its own monitoring at selected site visits to construction work sites. Some construction tasks had been sampled on numerous occasions by industrial hygienists while others, such as rock crushing, have received little attention.

Unlike many workers in general industry, construction workers perform tasks associated with silica exposure for widely varying periods in the course of an 8-hour shift, and the exposure monitoring data available for construction workers is frequently collected for less than a full shift. For example, construction workers might perform masonry cutting or hole-drilling for only a short portion of the shift, then perform activities that do not cause silica exposure for the remainder of the shift. Thus, many samples in the literature were taken over short durations.

To standardize the exposure monitoring results for comparison with a proposed 8-hour time-weighted average (TWA) PEL, ERG calculated the 8-hour TWA results for samples of duration less than 480 minutes. When it was available, ERG used information provided in the sampling studies to characterize the remainder of the workers' activities when sampling did not cover a full 8 hours. Where no further information was given, ERG assumed either that the worker had zero exposure for the remainder of the shift or that the worker had remained exposed at the same level for the unsampled portion of the shift. Please refer to the relevant exposure profile discussion for each task/worker category for information on how specific exposure sampling results were treated. In selected cases, ERG had to omit exposure monitoring data from the analysis: the source material provided insufficient information about the worker's activities to allow an assessment of the source and conditions in which the silica exposure occurred.

Table 3-1 presents a summary of 8-hour TWA respirable silica exposures of sampled workers for each job category mentioned above. The table also includes the range of actual sample durations associated with the sample results in each job category. As the table indicates, sample durations vary greatly within each job category. For example, sample durations for impact driller results range from 30 to 535 minutes. It should be noted that ERG used the TWA reading for the actual time sampled when the sample duration exceeded 480 minutes (rather than standardizing to an 8-hour TWA).

Table 3-2 summarizes the distribution of 8-hour TWA respirable quartz exposures in construction job categories. The results for each task/worker category are described in detail in the exposure profile sections.

Table 3-1

Summary of 8-hour TWA PBZ Respirable Quartz Exposures of Sampled Workers

Job Category	Number of Samples	Exposure Range * (μg/m³) Min	Exposure Range * (μg/m³) Max	Median (μg/m³)	Mean (μg/m³)	Sample Duration Range Min	Sample Duration Range Max
Drywall finishers	15	<=8	72	<12	17	82	734
Earth drillers	30	<=12	1,190	54	150	185	519
Grinders and tuckpointers using hand-held tools	148	<=12	75,153	442	1,670	56	524
Grinders	*41*	*14*	*4,414*	*178*	*653*	*56*	*524*
Tuckpointers	*107*	*<=12*	*75,153*	*526*	*2,060*	*72*	*482*
Heavy construction equipment operators	24	<=11	170	<12	30	190	535
Hole drillers using hand-held drills	9	<=12	286	60	74	45	479
Impact drillers	100	<=12	3,059	148	324	30	535
Masonry cutters using portable saws	74	<=11	10,318	65	312	43	545
Hand-held saw	*49*	*<=12*	*10,318*	*102*	*429*	*43*	*487*
Walk-behind saw	*22*	*<=11*	*461*	*39*	*108*	*53*	*545*
Vehicular saw	*3*	*<=12*	*88*	*33*	*45*	*70*	*125*
Masonry cutting using stationary saws	28	<=11	2,005	63	230	16	511
Millers using portable or mobile machines	6	<=11	340	<12	81	202	505
Rock-crushing machine operators and tenders	5	172	1,860	300	798	206	571
Underground construction workers	30	<=7	257	<12	39	399	775
Total	**469**	**<=7**	**75,153**	---	---	**16**	**775**

* Some 8-hour TWAs were calculated from short duration samples assuming zero exposure for unsampled period.
See Exposure Profile text for further information.
Sources: OSHA Special Emphasis Program inspection reports, NIOSH reports, and published and unpublished literature (see References).

Table 3-2

Distribution of 8-hr TWA PBZ Respirable Quartz Exposures of Samples Workers

Job Category	Number of samples (and percent of total) in given range * <=25 (μg/m³)	>25 to <=50 (μg/m³)	>50 to <=75 (μg/m³)	>75 to <=100 (μg/m³)	>100 to <=150 (μg/m³)	>150 to <=250 (μg/m³)	>250 to <=500 (μg/m³)	>500 to <=1000 (μg/m³)	>1000 (μg/m³)	Total Number (μg/m³)
Drywall finishers	13 87%	1 7%	1 7%	0 0%	0 0%	0 0%	0 0%	0 0%	0 0%	15 100%
Earth drillers	12 40%	3 10%	3 10%	2 7%	2 7%	4 13%	2 7%	1 3%	1 3%	30 100%
Grinders and tuckpointers using hand-held tools	7 5%	3 2%	5 3%	11 7%	18 12%	8 5%	27 18%	26 18%	43 29%	148 100%
Grinders	*1* *2%*	*2* *5%*	*2* *5%*	*4* *10%*	*10* *24%*	*3* *7%*	*8* *20%*	*4* *10%*	*7* *17%*	*41* *100%*
Tuckpointers	*6* *6%*	*1* *1%*	*3* *3%*	*7* *7%*	*8* *7%*	*5* *5%*	*19* *18%*	*22* *21%*	*36* *34%*	*107* *100%*
Heavy construction equipment operators	19 79%	1 4%	1 4%	1 4%	1 4%	1 4%	0 0%	0 0%	0 0%	24 100%
Hole drillers using hand-held drills	2 22%	2 22%	4 44%	0 0%	0 0%	0 0%	1 11%	0 0%	0 0%	9 100%
Impact drillers	13 13%	8 8%	8 8%	9 9%	14 14%	12 12%	22 22%	7 7%	7 7%	100 100%
Masonry cutters using portable saws	31 42%	8 11%	3 4%	3 4%	10 14%	8 11%	7 9%	1 1%	3 4%	74 100%
Hand-held saws	*20* *41%*	*4* *8%*	*1* *2%*	2 4%	*8* *16%*	*7* *14%*	*3* *6%*	*1* *2%*	*3* *6%*	*49* *100%*
Walk-behind saws	*10* *45%*	*3* *14%*	*2* *9%*	*0* *0%*	*2* *9%*	*1* *5%*	*4* *18%*	*0* *0%*	*0* *0%*	*22* *100%*
Vehicular saw	*1* *33%*	*1* *33%*	*0* *0%*	*1* *33%*	*0* *0%*	*0* *0%*	*0* *0%*	*0* *0%*	*0* *0%*	*3* *100%*
Masonry cutting using stationary saws	6 21%	7 25%	2 7%	5 18%	1 4%	0 0%	3 11%	3 11%	1 4%	28 100%

Table 3-2

Distribution of 8-hr TWA PBZ Respirable Quartz Exposures of Samples Workers

Job Category	Number of samples (and percent of total) in given range *									
	<=25 (μg/m³)	>25 to <=50 (μg/m³)	>50 to <=75 (μg/m³)	>75 to <=100 (μg/m³)	>100 to <=150 (μg/m³)	>150 to <=250 (μg/m³)	>250 to <=500 (μg/m³)	>500 to <=1000 (μg/m³)	>1000 (μg/m³)	Total Number (μg/m³)
Millers using portable or mobile machines	4 67%	0 0%	0 0%	1 17%	0 0%	0 0%	1 17%	0 0%	0 0%	6 100%
Rock-crushing machine operators and tenders	0 0%	0 0%	0 0%	0 0%	0 0%	1 20%	2 40%	0 0%	2 40%	5 100%
Underground construction workers	19 63%	5 17%	2 7%	1 3%	2 7%	0 0%	1 3%	0 0%	0 0%	30 100%
Total	**126** **27%**	**38** **8%**	**29** **6%**	**33** **7%**	**48** **10%**	**34** **7%**	**66** **14%**	**38** **8%**	**57** **12%**	**469** **100%**

* *Some 8-hour* TWAs were calculated from short duration samples assuming zero exposure for unsampled period. See Exposure Profile text for further *information.*

3.2 DRYWALL FINISHERS

3.2.1 Drywall Finishers: Process Description

After segments of drywall have been installed, drywall workers use a joint compound paste to seal the cracks between segments and to cover divots from nails. Once the joint compound is dried, workers sand the surface by hand to create a smooth finish. The drywall installer might perform the finishing, or a specialized tradesworker might perform this work. Sanding dried joint compound containing silica is believed to be the primary source of silica exposure in this job category.

The drywall itself contains little or no crystalline silica (U.S. Gypsum, 1999). Silica-free joint compounds have become widely available in recent years, but some products continue to contain crystalline silica. For example, NIOSH (NIOSH ECTB 208-11a, 1995) found that bulk samples of a commercially available joint compound contained up to 6 percent quartz, although crystalline silica was not listed on the material safety data sheet for the product. In another study, NIOSH determined that three of six drywall compounds purchased at a retail store contained minor or trace amounts of crystalline silica, while silica was not detected in the other three (NIOSH, 1997). Drywall finishing jobs in which NIOSH (1997) conducted air monitoring lasted from 1.5 hours to more than 8 hours per shift.

3.2.2 Drywall Finishers: Exposure Profile

To develop the exposure profile for drywall finishers, ERG relied on 15 sample results obtained by NIOSH during two separate field studies (NIOSH ECTB 208-11a, 1995; NIOSH, 1997). As Table 3-1 indicates, the median 8-hour TWA personal breathing zone (PBZ) respirable quartz concentration for drywall finishers is less than or equal to 12 $\mu g/m^3$ (below the limit of detection, or LOD, of 10 μg per sample). There were seven readings at or below the LOD. The mean concentration is 17 $\mu g/m^3$. The highest respirable quartz result among drywall finishers was 72 $\mu g/m^3$, obtained for a worker performing overhead sanding (NIOSH, 1997); this was the only reading greater than 50 $\mu g/m^3$.

The low silica exposure readings described above result from the use of silica-free joint compound or compounds with very low silica content. The potential for drywall workers to be exposed to higher levels, however, is indicated by a study which found that 22 percent of samples collected during OSHA inspections in the 1980s through the early 1990s in SIC 1742 (plastering, drywall, insulation) exceeded the current PEL (Roznowski, 1999).

3.2.3 Drywall Finishers: Technological Feasibility—Baseline Controls

Based on a review of NIOSH literature, drywall finishers typically perform their work indoors, use no engineering controls, and use a joint compound that contains little or no silica. Sanding is performed by hand or with a pole. No specific work practice controls were identified. All 15 drywall finishers in ERG's data set were working at baseline conditions, so the median, mean, and range described above apply (median $\leq 12\ \mu g/m^3$, mean $17\ \mu g/m^3$, range $\leq 12\ \mu g/m^3$ to $72\ \mu g/m^3$).

3.2.4 Drywall Finishers: Technological Feasibility—Additional Controls

ERG judged that the primary source of exposure for drywall workers is the use of silica-containing joint compounds. Where drywall finishers' exposures are elevated, the primary exposure control is substitution, i.e., changing to a joint compound that does not contain silica. NIOSH has indicated that there are a number of commercially available compounds that do not contain silica. ERG could find no reason why substitution would not be possible. But as stated earlier, some joint compounds that do not list silica as an ingredient might still contain small amounts of silica (NIOSH, 1997).

When drywall finishers find themselves using silica-containing joint compound, local exhaust ventilation (LEV) and wet methods are both options for dust control.

NIOSH tested the effectiveness of five off-the-shelf LEV systems: three designed to control dust during pole sanding and two to control dust during hand sanding. Total dust area sample results revealed that all five systems were effective for reducing total airborne dust by at least 80 percent, ranging up to 97 percent. The main reason for the lack of LEV use among drywall finishers appears to be price. (Prices for the controls used in NIOSH's study ranged from $15 to over $1,800). Other problems included ergonomic and maintenance issues. Furthermore, some LEV models include a water filtration bucket, so a water source would be required for their use (NIOSH ECTB 208-11a, 1995). Although respirable silica levels were not specifically measured, ERG believes that these LEV systems could also reduce respirable silica concentrations by 80 percent.

Wet methods are possible whenever a water source is available. A wet method might involve wiping a clean, damp sponge over the dry joint compound to smooth the seam. As the sponge becomes loaded with excess joint compound, the drywall finisher simply rinses the sponge in a bucket of water and squeezes excess moisture out. The water needs to be replaced when it has too much compound suspended in it to adequately rinse the sponge. Alternately, the dried joint compound can be wetted with a spray bottle, then sanded with sandpaper (NIOSH ECTB 208-11a, 1995). A common concern among drywall finishers is extended drying time, which can delay subsequent painting work. But drywall finishers commonly use heat guns (tools resembling hair blow-dryers without the airflow) for quick repair jobs. ERG believes this tool could be used to dry any compound that has not dried quickly enough. In spite of the ease of this process, wet methods are common only in some parts of the country (Ventura, 2001). Where they are not common, some finishers feel that the process takes too long (Flanagan, 2001; Ventura, 2001). Other finishers have concerns that the introduction of water at this stage of the process might harm the product (NIOSH, 1999; Ventura, 2001). Where they are used, wet methods are generally intended to protect property or persons other than the drywall finishers (Flanagan, 2001; NIOSH, 1999). ERG does not have data to quantify the effectiveness of wet methods during drywall finishing. However, based on the effectiveness of wet methods in reducing respirable silica concentrations in other job categories and other industries, and based on the low mean and median exposure levels among drywall finishers, ERG believes that the use of wet methods can be effective in controlling the respirable silica exposures of drywall finishers to levels well below 72 $\mu g/m^3$, the highest exposure identified.

3.2.5 Drywall Finishers: Technological Feasibility—Conclusion

ERG concludes that most workers who finish drywall are currently exposed to respirable crystalline silica exposure at levels less than 25 $\mu g/m^3$. Furthermore, this value of 25 $\mu g/m^3$ can be achieved by all drywall finishers who use drywall compound that does not contain silica. In the event that substitution is not possible, LEV and wet methods are other options.

Based on the reductions in total dust levels found by NIOSH (NIOSH ECTB 208-11a, 1995) when drywall finishers used sanding equipment fitted with LEV, ERG concludes that the respirable silica exposure of all drywall finishers can be reduced to levels below 25 $\mu g/m^3$. ERG calculated this conservative estimate by reducing the highest drywall finisher reading (72 $\mu g/m^3$) by 80 percent, the minimum amount by which LEV sanding equipment reduced respirable dust (NIOSH ECTB 208-11a, 1995).

Although ERG is not able to quantify the effectiveness of wet methods in reducing the exposure of drywall finishers who work with silica-containing joint compound, ERG concludes that wet methods will be at least as effective as LEV, likely reducing the exposures of all drywall finishers to levels below 25 $\mu g/m^3$. As demonstrated for most construction tasks, wet methods generally provide more effective and more reliable dust control than LEV. ERG presumes that wet sanding is particularly effective for controlling respirable silica, primarily because fine particles generated by this method do not become airborne.

3.2.6 Drywall Finishers: References

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3.3 EARTH DRILLERS (USING RIGS TO DRILL ROCK AND CONCRETE, EXCLUDING HAND-HELD AND TUNNEL-BORING EQUIPMENT)

3.3.1 Earth Drillers: Process Description

Earth drillers operate rigs to produce deep holes in rock or concrete. The holes, with diameters ranging from 2 inches to more than 6 inches, are used for demolition (to insert explosives or to weaken a structure to be cut or wrecked) or for structural support installation (e.g., rebar installation) (NIOSH, 1992c, 1992d, 1995; Zimmer, 1997). An earth driller either operates a rig from a vehicle equipped with a cab or stands beside the rig to operate the controls. The drills typically are equipped with compressed air, which is continuously forced through the bit's hollow core to "bail" rock or concrete dust and debris from the bottom of the hole. Larger pieces of debris that accumulate at the top of the hole are manually moved out of the way by the earth driller or a tender (Zimmer, 1997).

The earth driller operates a percussion (hydraulic or pneumatic) drill mounted to a movable arm on a tractor, truck, or other crawler or wheeled vehicle that serves as transportation and support for the attached drill (Zimmer, 1997). Rock drilling is normally a one-person job, but some applications require a second worker to fine-tune the drill position (NIOSH, 1995).

The earth driller operates controls to position the rig and bit and to initiate the drilling. The earth driller oversees the operation and intermittently makes adjustments using the rig's controls. A drilling operator working in an enclosed cab might open the cab's window while making the adjustment (Zimmer and Lueck, 1986). To produce a deep hole, extensions must be added to the bit, requiring the operator to stop the drill (typically for less than 5 minutes) each time an addition is needed (Zimmer, 1997). Depending on the substrate, as well as the required hole diameter and depth, the operator might take from a few minutes up to several hours to drill one hole. Data reviewed for this report indicate that workers perform drilling operations for a minimum of 1 hour to a maximum of 7 hours per day. In the NIOSH reports reviewed for this study, the drillers spent more than 75 percent of their work time on actual drilling and the rest on repositioning the drill and adding bit extensions (NIOSH 1992c, 1992d, 1995; NIOSH ECTB 233-122c, 1999).

3.3.2 Earth Drillers: Exposure Profile

The median 8-hour TWA PBZ respirable quartz concentration for 30 earth driller results is 54 $\mu g/m^3$, and the mean concentration is 150 $\mu g/m^3$, as Table 3-1 indicates.[1] The lowest respirable quartz readings, all reported as less than the LOD of 12 $\mu g/m^3$, were found in seven samples at four different sites. One of these samples represents work performed with no controls during a 382-minute period (NIOSH, 1995), while the others represent work performed with wet methods and/or LEV (NIOSH ECTB 233-120c, 1999; OSHA SEP Inspection Reports 300340908, 300576204, 301459095). The highest exposure reading, 1,190 $\mu g/m^3$, was obtained for an earth drilling assistant who stood outside at the back of the rig, positioning and controlling drills, during a 514-minute period (NIOSH, 1995). As Table 3-2 indicates, about 33 percent of the earth drillers sampled (10 of 30) are exposed to respirable quartz levels exceeding 100 $\mu g/m^3$.

3.3.3 Earth Drillers: Technological Feasibility—Baseline Controls

As explained above, baseline conditions for earth drilling operators and assistants include drilling outdoors on rock or concrete, working in open cabs or adjacent to rigs, and using no engineering controls or specific work practice controls.

Of the 21 exposure monitoring results for earth drillers summarized in Tables 3-1 and 3-2, ERG identified 17 readings associated with these baseline conditions, ranging from less than or equal to 12 $\mu g/m^3$ (the LOD) to 1,190 $\mu g/m^3$, with a median of 125 $\mu g/m^3$ and a mean of 219 $\mu g/m^3$ (NJDHSS, 2000; NIOSH, 1992d, 1995).

[1] Sources of exposure monitoring data: NJDHSS, 2000; NIOSH, 1992d, 1995; NIOSH ECTB 233-120c, 1999; NIOSH ECTB 233-122c, 1999; OSHA SEP Inspection Reports 300340908, 300576204, 301459095.

3.3.4 Earth Drillers: Technological Feasibility—Additional Controls

For earth drillers who operate rigs from inside cabs, ERG believes using properly sealed and ventilated enclosed cabs under positive pressure with filtered air is the primary additional control for reducing exposure.

Through simultaneous testing inside and outside cabs, Hall et al. (2002) showed that properly maintained environmental cabs can reduce airborne particulate concentrations inside the cab by greater than 90 percent. Bakke et al. (2002) reported a 90 percent decrease in PBZ respirable quartz levels in a study comparing Norwegian tunnel construction workers who used drills with cabs to those using drills without cabs. The average silica result for 22 workers using drills with closed cabs was 31 $\mu g/m^3$, compared to 273 $\mu g/m^3$ for three drill operators working without cabs. These averages are based on samples representing 5 to 8 hours of the workers' 10-hour shifts. In a separate study, Rappaport et al. (2003) obtained 46 results for operating engineers on 16 U.S. construction sites and found that use of ventilated cabs reduced respirable silica exposure approximately sixfold (80 percent). The median result for all operating engineers was 75 $\mu g/m^3$; presumably the level was substantially lower for engineers in ventilated cabs. The median sample duration in this study was 315 minutes.

Zimmer (1997) demonstrated that earth drilling performed with wet methods, dust collection, and enclosed cabs with slight positive pressure reduced respirable dust exposures (not specific for quartz) further than wet methods and dust collection without the enclosed cabs (180 $\mu g/m^3$ during a 67-minute period, versus a median of 425 $\mu g/m^3$ during two sampling periods lasting 48 and 50 minutes). As Linch and Cocalis (1994) note, enclosed cabs should be air-conditioned so that operators will not open doors and windows, defeating the cabs' ability to control dust. The Mine Safety and Health Administration (1997) recommends additional features that cabs should possess:

- Horizontal and vertical areas should be kept clean and free of debris.
- Door seals and closing mechanisms should work properly. Seals around windows and power line entries, and joints in the walls, floors, etc., should be tightly sealed.
- Air conditioners should be designed so that air comes in from the outdoors to create positive pressure and passes through a prefilter, then a high-efficiency particulate air (HEPA) filter.

Prefilters with American Society of Heating, Refrigeration, and Air-Conditioning Engineers efficiencies of 90 percent are common.

- Each HEPA filter must be changed when it reaches the manufacturer's final resistance value.

For earth drillers who operate rigs adjacent to the equipment, as well as for assistants working outside the rig, additional controls include the use of LEV systems at the point of dust generation and the application of water during drilling.

Page and Organiscak (1995; Organiscak and Page, 1996) evaluated the effectiveness of various dust control modifications on truck-mounted rock drills equipped with Rotoclone dry dust collectors at surface coal mining sites. The researchers attempted the following control methods to reduce respirable dust exposure: dry containment methods, wet methods, and worker positioning. For each method, the researchers sampled the same area twice—once using the control and once without the control. Although specific times for each method are not specified, the samplers generally were operated for 1 to 3½ hours. It should be noted that the study evaluated only respirable dust, not respirable quartz, and relied on area samples rather than PBZ readings.

Three versions of dry dust controls were observed. A Rotoclone combined with increased drill deck shroud containment and increased air flow reduced respirable dust levels—compared to a Rotoclone on its own—from 2,340 $\mu g/m^3$ to 860 $\mu g/m^3$ (63 percent). A vertical extension to the Rotoclone that released the uncaptured dust at a greater height (with no other controls in place) reduced downwind respirable dust from 1,220 $\mu g/m^3$ to 460 $\mu g/m^3$ (62 percent) and also appeared to reduce dust levels on the drill bench. Enclosing the hopper discharge with a shroud (no other controls in place) reduced respirable dust levels from 25,420 $\mu g/m^3$ to 4,940 $\mu g/m^3$ (80 percent).

Adding a low flow of water to the Rotoclone exhaust (with no other controls in place) reduced respirable dust from 27,200 $\mu g/m^3$ to 2,140 $\mu g/m^3$ (92 percent). In fact, this wet method appeared to be 29 percent more effective at reducing respirable dust levels than the three dry methods combined (840 $\mu g/m^3$ versus 1,180 $\mu g/m^3$).

Repositioning the operator away from the drill during the operation and out of the dust cloud reduced the level of respirable dust exposure from 1,510 $\mu g/m^3$ to 470 $\mu g/m^3$ (69 percent).

For earth drillers working during subfreezing conditions, it might be possible to add an environmentally acceptable antifreezing agent to the water supply, assuming that any staining caused by the agent will not cause the product to be rejected. Propylene glycol is an environmentally acceptable antifreeze (ATSDR, 1999). ERG was not able to quantify the effectiveness of this method in reducing exposure.

3.3.5 Earth Drillers: Technological Feasibility—Conclusion

Based on the low median exposure of earth drillers discussed in the exposure profile and on the exposure reduction observed by Zimmer (1997), Hall et al. (2002), Rappaport et al. (2003), and Bakke et al. (2002), ERG concludes that using well-sealed properly ventilated enclosed cabs can reduce the median full-shift PBZ respirable quartz exposures of earth drillers operating rigs from inside cabs to less than or equal to 50 $\mu g/m^3$. Such a cab should be configured to provide adequate viewing of the operation and should supply tempered air so that the operator does not have to open windows or doors while operating the rig. The drilling should be stopped before the operator or an assistant approaches the drill hole.

In spite of the limitations of the Page and Organiscak study, ERG believes that the study's information on the relative effectiveness of containment, positioning, and wet methods can be used to predict the effectiveness of these methods in controlling PBZ respirable quartz. ERG concludes adding a low flow of water to the exhaust from dry dust collectors might reduce the respirable quartz exposures of most earth drillers operating rigs outside cabs to a level below 50 $\mu g/m^3$. For sites where additional dust control methods are necessary, wet methods might be combined with various combinations of dry containment methods to achieve levels below 50 $\mu g/m^3$.

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3.4 GRINDERS AND TUCK-POINTERS (USING SMALL HAND-OPERATED OR HAND-GUIDED EQUIPMENT)

3.4.1 Grinders and Tuck-Pointers: Process Description

Grinders work the surface of concrete and/or masonry with hand-operated tools to smooth rough surfaces, impart texture to smooth surfaces, or reshape structures. They also remove concrete residues adhering to form surfaces. A typical hand-held grinding tool is about 12 to 18 inches long, with a rotating disk or blade at one end that abrades the surface. Most grinders use the flat part of a disk or cup to work the surface (surface grinding). Some workers use the edge of the blade to cut a slot in the work surface, often with an angle grinding tool. Typically, the grinder stands or kneels so that the work is between chest and eye level (OSHA SEP Inspection Reports 300097839, 302251921, 302348909; NIOSH ECTB 233-104c, 1999; Shields, 1999.) When grinding ceilings, the tool might be mounted to a wheeled stand that is pushed back and forth by the operator.

Workers grind concrete and other building materials during both new construction and renovation. Grinding is routinely performed on indoor surfaces as well as building exteriors. During new construction, grinders often smooth concrete walls and install utility slots before windows are installed, while the structure is still partially open.

Workers who grind concrete often do other work with concrete when they are not grinding. Typical activities include mixing and pouring fresh concrete. Grinders are also often involved in chipping, sawing, cleaning the work area, and "sacking." (NIOSH described sacking as follows: the worker mixes Portland cement with silica flour and places the powder in a burlap sack. The grinder then rubs the sack over the wetted concrete surface to seal small holes. [NIOSH ECTB 233-104c, 1999])

Other grinders perform tuck-pointing, a task ERG considers to be a specialized subset of grinding. The term refers to the building renovation process of removing of old mortar from between masonry units ("pointing") in preparation for replacement with new mortar. A grinders who performs tuck-pointing (hereafter referred to as a tuck-pointer) typically uses an angle grinder, cutting mortar with the edge of the blade. The worker often holds the tool against the chest, shoulders, or neck for support while the rotating grinding wheel (about 4 to 6 inches in diameter) is driven into the joints; this places the worker's breathing zone near the point of operation, in one case about 12 inches from the work surface (OSHA SEP Inspection Report 302251921). Once the grinding is finished, the tuck-pointing worker removes dust and debris from the joint. Brushing the joints is the most common method of dust removal (Stewart, 2000). Less commonly, workers use water or compressed air to remove dust from the joints.

At larger job sites, tuck-pointing is often performed by multiple workers standing a few feet apart. In such situations the workers might contribute to each other's respirable silica exposure. Although most tuck-pointing is performed outdoors, on the exteriors of brick buildings, tuck-pointers occasionally work inside shrouds intended to keep dust from spreading beyond the construction site. These conditions limit the speed with which dust disperses from a worker's breathing zone.

Tuck-pointers also prepare new mortar, a process that involves dumping and thoroughly mixing dry silica-containing mortar ingredients in a tub before adding water (International Masonry Institute, 1996). This process is another potential exposure source. Finally, most tuck-pointers typically spend a substantial portion of their shifts applying wet mortar to freshly ground joints. This activity does not normally generate airborne dust, but exposure might continue if workers upwind continue to grind.

A review of OSHA Inspection Reports and other documents shows that the amount of time during which grinders and tuck-pointers perform grinding ranges widely, from about 1 hour per shift up to a full 8-hour shift (or longer).[2]

[2]OSHA SEP Inspection Reports 108772393, 110606670, 122159312, 122308257/0034, 300442977, 300444635, 300970423, 301461018; NIOSH ECTB 233-118c, 1999; NIOSH ECTB 233-123c, 1999; Lofgren, 1993.

3.4.2 Grinders and Tuck-Pointers: Exposure Profile

Grinders and tuck-pointers are among the most highly exposed construction workers. This observation is consistent with the findings of Flanagan et al. (in press). As Table 3-1 indicates,[3] 8-hour TWA PBZ respirable quartz readings available to ERG range from less than or equal to 12 $\mu g/m^3$ (the LOD) to 75,200 $\mu g/m^3$. The median value for these results is 442 $\mu g/m^3$; the mean is 1,670 $\mu g/m^3$. Of the 148 readings available, 122 (about 82 percent) are greater than 100 $\mu g/m^3$, as Table 3-2 shows.

Separating results for grinders and tuck-pointers shows that the exposure levels of tuck-pointers tend to be higher than those of grinders. The 41 results for grinders range from 14 $\mu g/m^3$ to 4,414 $\mu g/m^3$, with a median of 178 $\mu g/m^3$ and a mean of 653 $\mu g/m^3$. These results were obtained from 13 construction sites.[4] In general, the 107 values for tuck-pointers are substantially higher. For this subgroup, the median 8-hour TWA respirable silica result is 526 $\mu g/m^3$, with a mean of 2,060 $\mu g/m^3$. The results for tuck-pointers were obtained at 34 construction sites.[5]

Of the six **tuck-pointer** results less than or equal to 25 $\mu g/m^3$, three were reported as less than or equal to the LOD of 12 $\mu g/m^3$. One of these LOD readings was obtained for a tuck-pointer using a ventilated shroud during a 472-minute sample period (NIOSH ECTB 233-123c, 1999). But readings as high as 6,200 $\mu g/m^3$ were obtained at the same site for other tuck-pointer using the same type of equipment

[3]Sources of exposure monitoring data: Lofgren, 1993; Minnesota OSHA MN-303473920, 2000; Minnesota OSHA MN-303476485, 2000; Nash and Williams, 2000; NIOSH ECTB 233-104c, 1999; NIOSH ECTB 233-123c, 1999; NIOSH, 2000a and b; OSHA SEP Inspection Reports 108772393, 110606670, 116192147, 116296468, 122121270, 122159312, 122308257/0034, 122317522, 300097839, 300098530, 300442977, 300444635, 300555026, 301461018, 302251921, 302348909, 302675806; Shields, 2000.

[4]Echt and Sieber, 2002; Lofgren, 1993; NIOSH ECTB 233-104c, 1999; NIOSH, 2002; OSHA SEP Inspection Reports 108772393, 122159312, 300442977, 300444635, 300555026, 302675806; NIOSH, 1998; Shields, 1999, 2000.

[5]Minnesota OSHA MN-303473920, 2000; Minnesota OSHA MN-303476485, 2000; NIOSH ECTB 233-123c, 1999; Nash and Williams, 2000; OSHA SEP Inspection Reports 110606670, 116192147, 116296468, 122121270, 122308257/0034, 122317522, 300097839, 300098530, 301461018, 302251921, 302348909; Shields, 1999, 2000.

and doing similar work, suggesting that work practices were a more significant factor than LEV-equipped grinders in controlling respirable quartz exposure at this site (NIOSH ECTB 233-123c, 1999).

The highest respirable quartz concentration obtained for workers in this job category is 75,200 $\mu g/m^3$, for a tuck-pointer grinding mortar during a 474-minute period; at this site two tuck-pointers worked together in an outdoor courtyard with limited air circulation and no dust control measures, using compressed air to clean the joints (Shields, 2000). This result is significantly higher than other levels reported for grinders or tuck-pointers. In fact, it is the highest respirable quartz concentration in all construction job categories reviewed for this report. The next highest readings, 12,600 $\mu g/m^3$ (Shields, 2000) and 8,120 $\mu g/m^3$ (Minnesota OSHA MN-303476485, 2000), were both obtained for tuck-pointers using no dust control measures.

At another tuck-pointing operation, an 8-hour TWA respirable quartz concentration of 4,000 $\mu g/m^3$ was obtained for a worker inside an enclosure performing tuck-pointing with an ineffective LEV system. (These controls are described in greater detail in the "Additional Controls" section of this job category) (NIOSH, 2000a). Respirable quartz concentrations ranging from 270 to 789 $\mu g/m^3$ were obtained for workers who wetted the walls before beginning tuck-pointing work (OSHA SEP Inspection Report 116192147; Shields, 2000).

One of the lowest 8-hour TWA results for surface **grinders** (40 $\mu g/m^3$) is associated with a 265-minute sample collected while the operator used hand-held grinding equipment fitted with a shroud and vacuum attachment (Echt and Sieber, 2002). However, higher respirable silica results (100 $\mu g/m^3$ and greater) were obtained for the same worker using the same control method. For example an 8-hour TWA result of 130 was reported for a 340-minute sample collected on a different day.

An elevated reading, 3,830 $\mu g/m^3$, was obtained for a surface grinder who pushed the tool on a wheel-mounted stand to grind concrete ceiling seams smooth in a mostly enclosed structure (OSHA SEP Inspection Report 300555026). By contrast, NIOSH obtained a result of 64 $\mu g/m^3$ for a concrete grinder who spent the entire 451-minute sampling period performing sacking (NIOSH ECTB 233-104c, 1999). These values suggest that grinding, not sacking, is the primary source of exposure for grinder operators. The lowest 8-hour TWA respirable silica result for grinders (14 $\mu g/m^3$) is also associated with a worker who, ERG assumes, also used a wheel-mounted tool (described as a gas-powered router). That worker was grinding asphalt during the 275-minute monitoring session (OSHA SEP Inspection Report 300442977).

Note that in this case, the silica content of the asphalt (20 percent) was comparable to the percentage usually found in concrete. For example, bulk samples of concrete contained 20 to 30 percent quartz at three different locations where workers performed uncontrolled grinding (OSHA SEP Inspection Reports 108772393, 122159312).

In general, results for grinders working indoors tend to be higher than levels reported for outdoor surface grinders. For example, among the data available to ERG, 8-hour TWA results ranged from 56 to 737 $\mu g/m^3$ for 15 grinders working outdoors without controls.[6] Two of the 15 results (13 percent) exceeded 500 $\mu g/m^3$. By contrast, 15 results between 81 and 3,830 $\mu g/m^3$ are associated with grinders working indoors with no controls other than general ventilation.[7] Of those 15 results, 7 (47 percent) exceeded 500 $\mu g/m^3$. ERG presumes that airborne respirable silica does not dissipate from the workers breathing zone as quickly indoors as outdoors, where air currents disperse dust.

3.4.3 Grinders and Tuck-Pointers: Technological Feasibility—Baseline Controls

ERG concludes that baseline conditions for workers performing surface **grinding** include dry grinding outdoors on concrete, using no engineering controls or specific work practices. Of the 41 samples summarized in Table 3-2, ERG identified 15 readings for grinders working at baseline conditions, which generated a median 8-hour TWA PBZ respirable quartz concentration of 162 $\mu g/m^3$ and a mean concentration of 248 $\mu g/m^3$. The results, obtained at seven sites, ranged from 56 $\mu g/m^3$ to 737 $\mu g/m^3$.[8]

Baseline conditions for **tuck-pointers** include dry tuck-pointing performed outdoors on mortar, with no engineering controls or specific work practices in place. ERG identified 74 readings for tuck-

[6]OSHA SEP Inspection Reports 108772393, 122159312, 300444635, 300442977, 302675806; Lofgren, 1993; NIOSH ECTB 233-104c, 1999.

[7]OSHA SEP Inspection Reports 122159312, 300555026; Lofgren, 1993; NIOSH, 1998.

[8]OSHA SEP Inspection Reports 108772393, 122159312, 300442977, 300444635, 302675806; Lofgren, 1993; NIOSH ECTB 233-104c, 1999.

pointers working at baseline conditions, associated with a median 8-hour TWA PBZ respirable quartz concentration of 538 $\mu g/m^3$ and a mean concentration of 1,567 $\mu g/m^3$. The results ranged from less than or equal to the LOD of 12 $\mu g/m^3$ to 12,620 $\mu g/m^3$; they came from 13 sources.[9]

ERG judged that engineering controls are rarely used by either surface grinders or tuck-pointers.

3.4.4 Grinders and Tuck-Pointers: Technological Feasibility—Additional Controls

The primary additional exposure controls available for grinders and tuck-pointers are wet methods, the use of LEV-equipped grinding tools, and improved work practices. The effectiveness and availability of these methods are discussed in the following paragraphs.

Information regarding the effectiveness of wet methods in controlling the respirable quartz exposures of grinders and tuck-pointers is limited, in part because wet methods are only infrequently used for grinding work in the construction industry. Nevertheless, NIOSH evaluated PBZ respirable silica while a surface grinder and helper smoothed concrete walls in a semi-enclosed construction site, with the helper constantly spraying water just ahead of the grinder blade. Compared to uncontrolled grinding at this site, grinding with the water spray reduced the exposure levels by 90 percent. The air sampling pump faulted and was replaced during the evaluation, so the sampling result of 20 $\mu g/m^3$ respirable silica might be biased downward (NIOSH, 1998). These results suggest that the exposure level during indoor grinding with wet methods was well below 100 $\mu g/m^3$ and likely below 50 $\mu g/m^3$. Note that during this test the circuit interrupt tripped several times, possibly because water entered a hole in the tool casing and caused an electrical short. Despite this complication, workers performed active grinding for approximately 75 percent of the 342-minute sampling period.

Pre-wetting a surface before grinding appears to be less effective than applying water continuously. Respirable quartz concentrations ranging from 270 to 789 $\mu g/m^3$ were obtained for workers

[9]OSHA SEP Inspection Reports 116192147, 116296468, 122308257/0034, 300097839, 300098530, 302251921, 302348909; Minnesota OSHA MN-303473920, 2000; MN-303476485, 2000; Lofgren, 1993; Nash and Williams, 2000; Shields, 1999, 2000.

who wetted the walls before beginning tuck-pointing work (OSHA SEP Inspection Report 116192147; Shields, 2000).

Some workers stated that grinding on a moist surface forms a thick slurry that impedes grinding and leaves a film on the work surface (OSHA SEP Inspection Reports 110606670, 300444695; ERG, 2002). But based on information obtained during a site visit to a masonry training facility, in which water-fed grinders were used to smooth terrazzo flooring (ERG, 2000), ERG believes that wet methods might be possible in certain environments. (In the case of the masonry training facility, two hand-held electric water-fed grinders—one abrasive-cup type and one wheel-type—were used on a horizontal surface where barriers had been erected to keep the resultant slurry contained. Perhaps the slurry, which was of a thin consistency and about one inch deep,"washed" the abrasive wheels to prevent the impedance described by others.) Furthermore, it appears it might sometimes be possible to clear slurry before the water evaporates. Additionally, by increasing water flow to the cutting surface, workers might be able to flush particles away from the work surface and prevent formation of slurry. Workers can remove any residual concrete particles by brushing the surface and rinsing. Depending on the amount of water required and the jurisdiction in which the work is performed, workers might need to collect the water to prevent run-off.

Exposure monitoring data from the cut stone industry (SIC 3281) also demonstrates the effectiveness of wet methods for controlling dust during grinding operations. Use of water reduced the average respirable quartz exposure levels of fabricators by 88 percent. Fabricators used water-fed angle grinders to grind granite countertops (Simcox et al., 1999). In this study of four granite shops that switched to water-fed equipment, average respirable quartz concentrations obtained for fabricators at each site were reduced to levels below 70 $\mu g/m^3$. ERG concludes that wet methods can be similarly effective in controlling the exposures of surface grinders.

For grinders able to use wet methods, subfreezing conditions might introduce an added complication. Continued work might be possible—as for earth drillers—if an environmentally acceptable antifreezing agent is added to the water supply, assuming that the substance is compatible with the work process. Propylene glycol is an environmentally acceptable antifreeze (ATSDR, 1999).

Despite the benefits of water for controlling dust during grinding, ERG concludes that wet methods might have limited applicability for tuck-pointing. A common concern among tuck-pointers is that the use of high volumes of water causes the joint compound to run down the bricks, making it necessary to spend additional time and money in cleanup efforts (Kassman, 2000; Stewart, 2000). The compound can be rinsed off the bricks before the water evaporates, but such a practice becomes more difficult as the height of the tuck-pointing work increases (Stewart, 2000). Wet methods also present liability issues, specifically related to the potential for debris-laden water to damage structures or to spray pedestrians (Stewart, 2000). At a tuck-pointing site evaluated by NIOSH (ECTB 233-119c, 1999), wet methods were not used because other contractors reported that dust-laden water had left a mortar film on the building and on nearby cars, and that the building's interior had become damaged when the dust-laden water leaked through windows and doors.

The use of LEV is another option for controlling the exposures of grinders and tuck-pointers. In a demonstration study, grinding equipment fitted with a shroud and vacuum reduced respirable quartz levels by 93 percent (Nash and Williams, 2000).

Proper design and work practices are critical to LEV, though, and NIOSH research found mixed success with this approach. NIOSH (1999—233-123c) reported full-shift PBZ respirable quartz levels ranging from less than 12 $\mu g/m^3$ (the LOD) to 6,200 $\mu g/m^3$ for tuck-pointers using grinders equipped with LEV shrouds. NIOSH considered the LEV systems ineffective in controlling respirable quartz exposures, surmising that the filter bags attached to the grinders' exhaust were not designed to collect respirable-size particles (NIOSH ECTB 233-123c, 1999).

NIOSH also found the LEV system at a masonry renovation construction site to be ineffective (NIOSH, 2000b). The angle-grinders were fitted with ventilated shrouds attached to 1-inch flexible hoses, which led to a settling chamber and exhaust fan. With this design, quartz PBZ exposures ranged from 100 to 4,500 $\mu g/m^3$. NIOSH hypothesized that the pressure drop through the system was too great for the fan, so that airflow was inadequate to capture dust. Furthermore, the air was discharged back into the workplace without passing through a filter that would have removed the respirable particles, which might have been discharged into the workplace.

As previously noted, Nash and Williams (2000) found that LEV can substantially decrease respirable silica levels. They sampled air during mortar grinding with and without a modified LEV dust collection shroud attached to the tool. An 8-hour respirable quartz reading of 4,080 $\mu g/m^3$ was obtained for a tuck-pointer performing uncontrolled mortar grinding. A reading of 306 $\mu g/m^3$ was obtained for a worker using the LEV-equipped grinder. The dust collection system consisted of a shroud on the grinder and a hose attachment leading to a collection bag. Although this study only monitored air for 1 to 2 hours (significantly less than full-shift), ERG concludes that similar effectiveness might be achieved for tuck-pointing workers performing activities for entire shifts, provided that filters are cleaned and bags are emptied as needed. It should be noted that although LEV reduced exposure significantly, the 306 $\mu g/m^3$ reading was still elevated. In part, this exposure level might be due to the fact that the workers occasionally used a leaf blower to blow dust off the work surface.

Several manufacturers of surface grinders and angle grinders currently offer LEV options (Krenzer, 2000; Trelawny, 2001; Shave-Away, Europe, 1999). Other companies specialize in manufacturing after-market ventilation systems for various hand-held tools (DustControl AB, 1999; Shave-Away, Europe, 1999). Commercially available shrouds for grinding tools have been evaluated both under experimental conditions and at construction sites.

Croteau (2000) and Croteau et al. (2002) reported a respirable silica reduction of 93 percent during flat surface grinding with a 5.5-inch wheel under experimental conditions. In those studies, 15-minute tests were conducted in an enclosed test area. Although the exposure reduction was substantial, the shroud and vacuum did not control dust completely: there was still substantial exposure to respirable silica. With a higher airflow rate, the shroud might have captured dust more effectively; however, the vacuum was operating at peak capacity, approximately 75 cubic feet per minute (CFM). This flow rate was about half the volume of 25 CFM per inch of blade diameter (equal to 138 CFM in this case) recommended by ACGIH (2001).

NIOSH (1998) reported reductions of 75 to 90 percent for three different shroud/vacuum combinations (760 to 900 CFM) attached to angle grinders under actual workplace conditions. Workers operated the grinders for 65 to 85 percent of the study's 2- to 3-hour sampling periods. In a separate study (NIOSH EPHB 247-21, 2002), NIOSH investigators found that with a vacuum air flow of 122 CFM, several combinations of shrouds and grinders reduced respirable dust by an average of 90 percent compared to uncontrolled grinding at the same two construction sites. Respirable silica results for the three operators were all below 40 $\mu g/m^3$ during the grinding periods evaluated (again 2 to 3 hours). Meanwhile, results of short-term samples (covering grinding periods only) collected by Akbar-Khanzadeh and Brillhart (2002) suggest that average silica exposure was approximately 75 percent less for grinder operators using vacuum dust control (average result: 38 $\mu g/m^3$) compared to those using no controls (1,500 $\mu g/m^3$). This study evaluated 17 workers using 4.5-inch angle grinders at several different construction sites. (Note that it was designed to evaluate variables other than shroud efficiency.)

Echt and Sieber (2002) collected air samples on 5 days when a single worker used various grinders fitted with a single model of dust collection shroud. Breathing zone respirable silica levels ranged from 65 to 200 $\mu g/m^3$ during the 2- to 3- hour periods of concrete grinding. The worker operated the grinders for two sessions per day (4 to 6 hours daily), resulting in 8-hour TWA values of 36 to 130 $\mu g/m^3$ (NIOSH EPHB 247-15c, 2002; Echt and Sieber, 2002). For this evaluation, the commercially available shroud was attached to a vacuum with reported filter efficiency of 99.99 percent for particles 1 to 3 micrometers in diameter. NIOSH (2001—EPHB 247-15) obtained slightly higher results for a worker smoothing concrete inside a parking structure using various combinations of grinding equipment, shrouds, and vacuums. Six-hour samples resulted in 8-hour TWA respirable quartz readings of 142, 155, and 208 $\mu g/m^3$ on separate days. For comparison, a period of uncontrolled grinding was evaluated at a similar site, where high dust levels would not interfere with other workers. That 301-minute sample indicated an 8-hour TWA silica result of 1,730 $\mu g/m^3$ (2,750 $\mu g/m^3$ during the period of actual grinding).

Although LEV-equipped grinders are believed to be applicable in most operations, the shroud might prove difficult to use during certain operations, such as grinding on corners or on curved surfaces like columns. The need for frequent emptying of dust collection devices might also limit their usefulness (NIOSH ECTB 233-123c, 1999; Croteau, 2000). Moreover, the tuck-pointers in the Nash and Williams demonstration study indicated that the LEV equipment forced them to slow the speed of their work, putting them at an economic disadvantage (Nash and Williams, 2000).

A combination of wet methods and LEV provide an additional option for dust control. NIOSH (2000—ECTB 247-12) conducted air sampling while a worker operated a tuck-pointing grinder fitted with a ventilated shroud and a small water application nozzle. Water was applied at a rate of 26 ounces (nearly 1 quart) per minute. This equipment reduced the respirable dust level to 380 $\mu g/m^3$, which is at least 93 percent lower than values of 5,000 to 16,000 $\mu g/m^3$ reported for uncontrolled tuck-pointing at a different site in the same study. During the 1-hour test, sample filter loading was too low to analyze for quartz content. .

As mentioned previously, proper work practices are critical to achieving optimal control with LEV-equipped grinders. The following work practices are recommended for controlling the respirable quartz exposures of tuck-pointers using grinders equipped with ventilation shrouds (Croteau, 2000; NIOSH ECTB 233-118c, 1999). These work practices emphasize the need to keep the shroud flush against the work surface as much as possible.

- Blade insertion: By placing the left-hand side of the shroud against the working surface before blade insertion, a worker can direct dust generated by the blade's high velocity into the shroud as the blade is pushed into the mortar joint.
- Blade depth: By maintaining the full depth of cut into the mortar that the tool allows, a worker can keep the shroud flush against the working surface, minimizing the space from which dust can escape.
- Grinding direction: By grinding from right to left, a worker can minimize the amount of dust escape using the direction of blade rotation. (Tuck-point grinding usually occurs from left to right, counter to the rotation of the blade.) Workers should refrain from moving the grinder back and forth, instead moving in only one direction.
- Force: By using nominal (not excessive) force, a worker can keep the leading edge of the tool blade and shroud flush against the working surface, minimizing the space from which dust can escape is minimized.
- Blade removal: By moving the tool slowly 5 to 10 centimeters to the right while removing it from the mortar joint, a worker can clear dust that has accumulated at the end of the joint. Workers should avoid repeated blade insertion and removal.

Although the effectiveness of improved work practices in reducing exposures has not been quantified, ERG concludes that such practices can reduce exposure significantly. For example, NIOSH obtained exposures at one construction site showing that, although most tuck-pointers were overexposed to respirable quartz, the readings were less than 12 $\mu g/m^3$ (the LOD) for a bricklayer and an apprentice who spent the entire shift grinding mortar joints between bricks (NIOSH ECTB 233-123c, 1999). By contrast, other workers at the site using the same type of grinding equipment and performing similar activities were exposed to respirable quartz levels ranging from 250 $\mu g/m^3$ to 6,900 $\mu g/m^3$ (obtained for an apprentice). Since the workers reportedly performed similar activities using the same type of tools, ERG concludes that the difference in exposure levels is related primarily to work practices.

Workers who stay upwind of their work can reduce their dust exposure; a state OSHA compliance officer who measured silica exposures above the current PEL at a tuck-pointing operation recommended upwind positioning as another work practice option to help reduce exposures (Minnesota OSHA MN-303476485, 2000). Because workers who use portable grinding tools occasionally move around and change direction, it might occasionally be possible for them to orient themselves upwind. ERG has no data, however, with which to quantify the effectiveness of this control and believes that it is unlikely that this method can reliably and routinely control the respirable quartz exposures of tuck-pointers.

The use of compressed air for removing excess mortar dust from joints can contribute significantly to elevated exposures for tuck-pointers (Shields, 1999). Workers can instead clean joints by brushing or rinsing with water (International Masonry Institutes, 1996). Water from a hand-held spray bottle is sufficient for joint cleaning. Workers might remove dust by vacuuming surfaces.

3.4.5 Grinders and Tuck-Pointers: Technological Feasibility—Conclusion

ERG concludes that by using wet methods, such as water-fed grinding equipment, most workers who operate **grinding** equipment can achieve respirable quartz levels below 100 $\mu g/m^3$. This is based on experiences in the cut stone industry (SIC 3281), in which the average result for fabricators was reduced to 60 $\mu g/m^3$ when workers used water-fed grinding and polishing equipment (Simcox et al., 1999). Additionally, a worker grinding concrete with water-spray dust control achieved exposure levels that, while not completely quantified, were well below 100 $\mu g/m^3$ and likely below 50 $\mu g/m^3$ (NIOSH, 1998). Hand-operated water spray equipment is readily available, as is water-fed grinding equipment for use in the cut stone products industry. ERG believes that an increased water flow rate would prevent slurry from thickening to a troublesome level. Furthermore, using pneumatic tools or taking steps to prevent water from entering electric tools would eliminate possible problems with short-circuits in grinding equipment. Note that ground fault interrupts would still be required, as they are anywhere electrical equipment is used near a source of water.

LEV will also reduce the respirable silica exposure levels of workers performing grinding with hand-held equipment. ERG cannot state with certainty that this control option will reliably reduce exposures to levels below 100 $\mu g/m^3$. A combination of controls, such as LEV and respiratory protection, will be required for worker protection. A half-facepiece respirator might be adequate when used in combination with LEV dust control for grinding equipment.

As the exposure profile indicates, the group of grinders who perform **tuck-pointing** are frequently exposed to extremely high respirable quartz levels. ERG concludes that the use of LEV-equipped grinding tools might reduce worker exposure, but the available data are an inadequate basis for a conclusion that most tuck-pointers could achieve levels of 100 $\mu g/m^3$ or less using this control method. An LEV-equipped grinder was associated with a short-term respirable quartz reading of 306 $\mu g/m^3$, a reduction of 93 percent when compared with the respirable quartz level of 4,080 $\mu g/m^3$ for tuck-pointing without the dust collection system in place (Nash and Williams, 2000).

ERG concludes that work practices can have a significant impact on the respirable quartz exposure levels of tuck-pointing workers using LEV, based on full-shift LOD readings of ≤ 12 $\mu g/m^3$ and 15 $\mu g/m^3$

obtained for two tuck-pointing workers at site evaluated by NIOSH (ECTB 233-123c, 1999) and another reading of 16 μg/m³ from Minnesota OSHA data (Minnesota OSHA MN-303473920, 2000). ERG believes that proper work practices in combination with well-designed LEV systems or wet methods, as well as ceasing to use compressed air to clean joints, can control tuck-pointers' exposures to a level at which a half-facepiece respirator might be adequate.

A combination of wet methods and LEV might control worker exposures to levels below 100 μg/m³. ERG judges, however, that the combination of both water and vacuum lines might make the grinding equipment awkward to handle during jobs that require precision grinding.

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3.5 HEAVY CONSTRUCTION EQUIPMENT OPERATORS

3.5.1 Heavy Equipment Operators: Process Description

A tractor operator drives a crawler or rubber-tired tractor and maneuvers attached pieces of large construction equipment. Attachments include (but are not limited to) augers, backhoes, buckets, cranes, dozer blades, draglines, forklifts, graders, rippers, rollers, scrapers, shovels, and trenchers (Russell, 1985). The category also includes dump-truck drivers, as well as operators of other heavy construction equipment (e.g., power cranes and power shovels). ERG is analyzing these workers together, based on the assumption that the activities associated with potential silica exposure are similar for all such heavy equipment operators. These tasks include displacement, loading, and dumping of rock, soil, and other construction materials and debris.

Some tractors and other construction equipment are equipped with enclosed cabs. However, ERG was not able to estimate the number of workers who operate heavy equipment using an enclosed cab. OSHA Inspection Reports and other studies consistently show that heavy equipment operators perform their tasks for more than 7 hours per shift.[10]

3.5.2 Heavy Equipment Operators: Exposure Profile

The 24 8-hour TWA PBZ respirable quartz readings obtained for operators of tractors and other heavy construction equipment range from less than or equal to 11 $\mu g/m^3$ (the LOD) to 170 $\mu g/m^3$; the median is 12 $\mu g/m^3$ and the mean is 30 $\mu g/m^3$, as Table 3-1 shows.[11] Of these 24 results, 17 values obtained from six sites were reported as less than or equal to 12 $\mu g/m^3$. One of these LOD readings was obtained for an excavator operator who was excavating asphalt and loading it into dump trucks during a 510-minute period on a rainy day. At this site, calcium chloride was routinely spread on the unpaved

[10]OSHA SEP Inspection Reports 116179359, 122212079; Greenspan et al., 1995; NIOSH HETA 93-0696-2395, 1994; NIOSH ECTB 233-120, 1999c; NIOSH ECTB 233-122c, 1999.

[11]Sources of exposure monitoring data: Greenspan et al., 1995; NIOSH, 1994, 1995; NIOSH ECTB 233-117c, 1999; NIOSH ECTB 233-120c, 1999; NIOSH ECTB 233-122c, 1999; OSHA SEP Inspection Reports 113455166, 116179359, 122212079, 300108495, 301186243.

roadbed surface to suppress dust (NIOSH ECTB 233-120c, 1999). Two other results of less than or equal to 12 $\mu g/m^3$ were associated with an operator (sitting in a cab with the door open) using a track-drive tractor fitted with an impact hammer to break large rocks (NIOSH ECTB 233-122c, 1999). At another site, NIOSH obtained the same low result for a backhoe operator digging sandstone from a blast hole (NIOSH, 1994).

Three results for heavy equipment operators exceed 50 $\mu g/m^3$: 54, 128, and 170 $\mu g/m^3$. The highest of these readings was obtained for a bulldozer/grader operator who performed excavation work. The operator presumably worked in an open cab during a 511-minute period. At this site, a water truck was used to wet the ground "at frequent intervals" (Greenspan et al., 1995). As Table 3-2 indicates, only 2 out of 24 readings (about 8 percent) obtained for tractor and heavy equipment operators exceeded 100 $\mu g/m^3$; 19 out of 24 readings (about 79 percent) were less than 25 $\mu g/m^3$.

3.5.3 Heavy Equipment Operators: Technological Feasibility—Baseline Controls

A review of OSHA, NIOSH, and other published reports indicates that construction workers who drive or otherwise operate tractors or other heavy construction equipment typically work outdoors without using wet methods, other engineering controls, or specific work practice controls. When workers operated equipment from inside cabs, windows were open, diminishing the effectiveness of the isolation provided by the cabs. ERG identified seven readings obtained for people working under these baseline conditions. The readings ranged from less than or equal to 11 $\mu g/m^3$ to 54 $\mu g/m^3$, with a median of less than or equal to 12 $\mu g/m^3$ and a mean of 19 $\mu g/m^3$ (NIOSH, 1995; OSHA SEP Inspection Report 122212079). These data suggest that activities in this job category generate low levels of respirable quartz relative to the respirable quartz levels associated with earth drilling or rock crushing.

3.5.4 Heavy Equipment Operators: Technological Feasibility—Additional Controls

Where heavy equipment operators' respirable quartz exposures are elevated, properly ventilated enclosed cabs and wet methods are options for reducing exposure levels. ERG believes that using a properly sealed and ventilated enclosed cab under positive pressure with filtered air is the primary additional control for reducing exposure. Although the effectiveness of enclosed, ventilated cabs has not been evaluated for heavy equipment operators, ERG believes this job category is analogous to that of earth drillers and that the analysis of enclosed cabs as a control measure for earth drillers applies to workers in this job category as well.

As Section 3.3.4 states, ERG believes that using a properly sealed and ventilated enclosed cab under positive pressure with filtered air is the primary additional control for reducing exposure for earth drillers who operate rigs from inside cabs. This conclusion is based, as discussed above, on studies by Rappaport et al. (2003), Hall et al. (2002), and Bakke et al. (2002)."]

As Linch and Cocalis (1994) note, enclosed cabs should be air-conditioned so that operators will not open doors and windows, defeating the cabs' ability to control dust. The Mine Safety and Health Administration (1997) recommends additional features that cabs should possess:

- Horizontal and vertical areas should be kept clean and free of debris.
- Door seals and closing mechanisms should work properly. Seals around windows and power line entries, and joints in the walls, floors, etc., should be tightly sealed.
- Air conditioners should be designed so that air comes from outdoors to create positive pressure and passes through a prefilter, then a HEPA filter. Prefilters with American Society of Heating, Refrigeration, and Air-Conditioning Engineers efficiencies of 90 percent are common.
- HEPA filters must be changed when they reach the manufacturer's final resistance value.

ERG has few data on heavy equipment operators using only purposeful wet methods during operations. The only example of purposeful wet methods during the dust-generating activity was recorded for a crane/hammer operator who was sitting in an enclosed cab and breaking concrete outdoors while a laborer sprayed water on the concrete. Additionally, the compliance safety and health officer noted that breeze blew dust away from workers. The operator's exposure was less than the LOD of 12 $\mu g/m^3$ (OSHA SEP Inspection Report 300108495). ERG cannot quantify how effective each of the three factors was in reducing dust levels, but this example implies that the combination of an enclosed and ventilated cab, an appropriately aimed water spray, and upwind worker positioning could be an extremely effective means of dust control.

In 14 out of 17 cases in which water or another dust suppressant was sprayed on the ground periodically and/or in which recent precipitation had wetted the ground, exposures of 15 $\mu g/m^3$ or less were recorded (OSHA SEP Inspection Report 301186243; NIOSH ECTB 233-120c, 1999; NIOSH ECTB 233-122c, 1999). In the remaining three cases, exposures were elevated in spite of wet methods. In one case, a water truck wetted the site "at frequent intervals," but a worker operating a bulldozer/grader during excavation had a respirable quartz exposure of 170 $\mu g/m^3$ (Greenspan et al., 1995). At another site where the ground was moist from previous precipitation, two workers were exposed to respirable quartz levels of 85 $\mu g/m^3$ and 119 $\mu g/m^3$ while operating a forklift for approximately 80 percent of the shift and mixing cement for approximately 20 percent of the shift (NIOSH ECTB 233-117c, 1999). ERG cannot determine whether these elevated exposures were caused in greater part by the dust stirred by the forklift or by the mixing of cement.

3.5.5 Heavy Equipment Operators: Technological Feasibility—Conclusion

ERG concludes that the respirable quartz exposures of heavy equipment operators can be reduced to 50 $\mu g/m^3$ or less, with no specific work practices or engineering controls in place. The median full-shift PBZ result of less than or equal to 11 $\mu g/m^3$ (the limit of detection) supports this assertion.

Where additional controls are needed, properly ventilated enclosed cabs or wet methods can help heavy equipment operators achieve levels below 50 $\mu g/m^3$. This conclusion is based in part on the preliminary finding that operators of such equipment typically generate little respirable quartz compared with earth drillers or rock crushers. ERG believes similar exposure levels can be achieved for heavy equipment operators using enclosed cabs in the construction industry.

3.5.6 Heavy Equipment Operators: References

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3.6 HOLE DRILLERS (USING HAND-HELD EQUIPMENT)

3.6.1 Hole Drillers: Process Description

Construction workers use hand-held drills to create pilot holes for anchors, bolts, and other means of attachment. Holes are sometimes drilled in large slabs of concrete to assist in lifting the slabs. A worker operating a common drill and a rotary bit may employ a technique known as pecking, in which the operator removes the drill briefly from the hole and continues to run the drill to allow the accumulated chips and dust to fly off the rotating bit (White, 1977). A rotary hammer or a percussion hammer, described below in Section 3.7.1 (Impact Drillers: Process Description), can also be used to drill holes. The portability and light weight of these drills allow the worker to operate them at any angle. Occasionally, hole drillers use compressed air to remove dust from holes (Hallin, 1983).

A review of OSHA inspection reports and other documents indicates that drilling may be performed only briefly or intermittently or might be done continuously during the work shift (Lofgren, 1993; NIOSH, 1993; NIOSH ECTB 233-123c, 1999; OSHA SEP Inspection Reports 103011359, 300035557). For example, an OSHA report (OSHA SEP Inspection Report 103011359) noted that workers could drill one hole per minute, with 40 seconds for the actual drilling and 20 seconds for repositioning the drill for the next hole. The worker in this report drilled holes for less than 1 hour on one day and drilled for 7 hours on the next.

Concrete coring, involving stabilized equipment used with copious amounts of water to produce a large hole, is not discussed in this section.

3.6.2 Hole Drillers: Exposure Profile

As Table 3-1 indicates, the nine full-shift PBZ respirable quartz readings for hole drillers using hand-held tools range from less than the LOD of 12 $\mu g/m^3$ to 286 $\mu g/m^3$, with a median of 60 $\mu g/m^3$ and a mean of 74 $\mu g/m^3$. The two lowest exposure readings were obtained for two workers who spent an entire 8-hour shift alternately drilling ½-inch holes through brick and steel and installing masonry anchors in exterior and courtyard walls (NIOSH ECTB 233-123c, 1999). Two other LOD readings, reported at less than or equal to 67 $\mu g/m^3$ and 69 $\mu g/m^3$, were obtained for workers drilling a concrete floor indoors with pneumatic drills to make holes to help lift out floor sections. The sample filter media were changed several times during the 6-hour sampling period, accounting for the higher LODs for these samples (OSHA SEP Inspection Report 103011359). These two results likely skew the median to a level somewhat higher than it would have been had the individual sampling segments been longer. The highest reading obtained for workers in this job category, 286 $\mu g/m^3$, was recorded for a worker drilling holes in the floor of a concrete parking garage where air circulation was poor (Lofgren, 1993). As Table 3-2 shows, this is the only result exceeding 100 $\mu g/m^3$. The remaining values are all less than 75 $\mu g/m^3$.

3.6.3 Hole Drillers: Technological Feasibility—Baseline Controls

A review of OSHA and NIOSH reports, as well as other published and unpublished reports, indicates that construction workers performing hole drilling most commonly work indoors on concrete and use no engineering controls or dust-suppressing work practices. Of the nine TWA PBZ respirable quartz readings summarized in the exposure profile, six—ranging from 41 $\mu g/m^3$ to 286 $\mu g/m^3$—represent hole drilling under these baseline conditions (Lofgren, 1993; OSHA SEP Inspection Report 103011359). The median is 63 $\mu g/m^3$ for this group and the mean is 95 $\mu g/m^3$.

3.6.4 Hole Drillers: Technological Feasibility—Additional Controls

As the previous section indicates, the baseline median exposure reading for hole drillers is 63 $\mu g/m^3$, associated with dry drilling indoors. LEV is the primary option available for reducing the exposure level of hole drillers. ERG has identified data indicating the effectiveness of LEV for use with rotary and percussion hammers.

Shepherd and Woskie (2003) found that, compared to uncontrolled drills, drills designed with dust collection cowls reduced respirable dust at least 90 percent when the cowls were connected to portable vacuums. Four combinations of different cowls and vacuums were tested during multiple15-minute trials. For each trial, the worker drilled a constant number of holes in a vertical concrete wall. Due to the short sampling time, the amount of respirable dust on the sample media could not be analyzed for crystalline silica. Average respirable dust levels ranged from 130 to 360 $\mu g/m^3$ when the vacuum and shroud were used, compared to 3,680 $\mu g/m^3$ without the control. Respirable quartz levels would have been lower. Interestingly, hammer drill design (as described by the manufacturer) included an internal air moving system and a filter sock that collected dust. For this study, however, the sock was removed and a vacuum hose connected. ERG believes that the design as tested likely collected respirable dust more efficiently due to the greater suction provided by the vacuum. Furthermore, tool-based dust collection socks generally do not retain dust as well as many of the filters available for vacuums. Particles escaping from a sock are released inches from the worker's breathing zone and can contribute to worker exposure.

The practice of sweeping or brushing debris from the hole appears to contribute to the exposure of workers drilling in concrete. In the study just described, a pilot study indicated that respirable dust concentration were cut to 50 percent of the original level when the worker stopped sweeping the wall after each hole was drilled (Shepherd and Woskie, 2003).

Hallin (1983) evaluated rotary and percussion hammers equipped with various LEV systems and various drill bit sizes. During the study the tools were operated indoors, where they were used to drill holes of various depths. The study showed that the use of LEV resulted in a 57 percent reduction in the median estimated respirable quartz exposure level for workers drilling 50-millimeter-deep holes in concrete with 6-millimeter drill bits (from a median of 140 $\mu g/m^3$ without LEV to a median of 60 $\mu g/m^3$ with LEV-equipped tools). Hallin found an 85 percent reduction in the median respirable quartz exposure level for workers drilling 80-millimeter-deep holes in concrete with 10-millimeter drill bits (295 $\mu g/m^3$ without LEV versus 45 $\mu g/m^3$ with LEV). In this study, each LEV system consisted of a suction-type connection and a dust extractor. Hallin's test readings represent actual sampling times (rather than calculated 8-hour TWAs), and were based on short sample durations (ranging from 60 to 180 minutes). Additionally, respirable crystalline silica levels were estimated from a composite of several respirable dust samples collected at the test site and using individual respirable dust samples obtained near, but not in, the workers' breathing zones. Compressed air was not used to clean the holes during these tests.

Fletcher (1989) reported that a telescoping cowl is more flexible than either a hood surrounded with flexible bristle skirting or a hard-sided extraction cowl, and that such flexibility affords better dust control. A review of Hallin's photographs and Fletcher's diagrams indicates that Hallin's study evaluated hard-sided extraction cowls. Telescoping cowls may reduce exposures more effectively than the LEV used in the Hallin study. ERG has not been able, however, to quantify the effectiveness of this LEV design in further reducing exposure.

3.6.5 Hole Drillers: Technological Feasibility—Conclusion

ERG notes that the current exposure level of most hole drillers is less than 75 $\mu g/m^3$, based on the median result of 63 $\mu g/m^3$ for workers who perform drilling with hand-held equipment. Data from Shepherd and Woskie (2003) suggest that workers who are currently exposed to levels above 75 $\mu g/m^3$ can reduce their exposure by approximately 50 percent by eliminating the practice of blowing or dry sweeping drilling debris from the work surface. Portable vacuums might be used instead. This 50 percent reduction would reduce eight of the nine values from the exposure profile to levels well below 50 $\mu g/m^3$.

ERG concludes that hole drillers who spend most of their shifts drilling holes indoors will need tools designed with LEV dust extraction features. By using this type of equipment, all hole drillers can achieve levels of 50 $\mu g/m^3$ or lower. The value of 60 $\mu g/m^3$ is the higher of Hallin's (1983) two estimated medians for hole drillers using LEV under experimental conditions. This median likely overestimates exposure: it assumes continuous exposure at the level found in a short-term sample. In reality, even when drilling is the worker's primary task, most hole drillers take breaks to reposition equipment, change location, or perform related activities, rather than drilling without interruption. Furthermore, as discussed above, flexible, telescoping cowls should control exposure better than the equipment tested by Hallin (1993).

To consistently achieve respirable silica levels at or below 50 $\mu g/m^3$, ERG believes, workers who perform intensive hole drilling in enclosed areas (where air circulation is poor) will need to use portable vacuum connections to their shrouds (rather than dust collection socks). For drills designed with shrouds and connected to portable vacuums, respirable dust levels were at least 90 percent lower than uncontrolled drills. For example, this method could reduce the highest result associated with a drill operator (286 $\mu g/m^3$) to approximately 30 $\mu g/m^3$.

3.6.6 Hole Drillers: References

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3.7 IMPACT DRILLERS (OPERATING BREAKER HAMMERS, DRILL HAMMERS, PERCUSSION HAMMERS, AND/OR ROTARY HAMMERS TO CHIP OR BREAK MATERIALS)

3.7.1 Impact Drillers: Process Description

Workers who use impact drills and related chipping equipment to chip and break rocks or concrete are exposed to silica primarily as a result of the force of high-speed, short-duration repetitive blows delivered to the silica-bearing material. (Construction workers who use hand-held impact drills for drilling small holes are discussed in Section 3.6.) The impact drills can be either electric or air-powered.

For work on surfaces less than about 3 inches thick, an impact driller typically uses a rotary hammer or a percussion hammer. These hammers are operated as common drills are, except that they are held with two hands—one hand on a separate handle in front of the other. Workers can hold them any angle, at almost any orientation to the body, and typically remain in close proximity to the point of operation to view the work.

A breaker hammer (commonly known as a jackhammer) is used for heavier-duty demolition and excavation. In the typical jackhammering stance, the worker stands and holds the side-by-side grips against the hips or thighs, with the shaft of the tool vertical. This puts the worker's face about 4 or 5 feet away from the tip of the jackhammer, the source of silica generation. A review of OSHA inspection reports, however, shows that a jackhammer operator can assume a variety of other positions in relation to the tool and the work. Some workers kneel on the working surface or sometimes bend over to hold the jackhammer almost parallel to the working surface. Jackhammer operators might also hold smaller impact drills perpendicular to their bodies, or hold the tools upside-down to chip away material at chest or face level.

Workers might perform impact drilling for only part of their shifts (2 or 3 hours per day) but typically perform such operations for 5 to 7 hours per shift, based on a review of selected OSHA inspection reports. During larger jobs, two or more workers might perform chipping simultaneously, which can increase the cumulative airborne dust in the local area. Impact drillers frequently use dry sweeping to clear larger chipping debris from the work area and use hand-held blowers or compressed air to remove fine dust from the chipped surface.

3.7.2 Impact Drillers: Exposure Profile

As Table 3-1 indicates, the full-shift respirable quartz readings for impact drillers range from less than or equal to the LOD of 12 μg/m³ to 3,059 μg/m³, with a median of 148 μg/m³ and a mean of 324 μg/m³.[12] About 61 percent of the sampled impact drillers (62 of 100) are exposed to 8-hour TWA respirable quartz levels greater than 100 μg/m³, as Table 3-2 shows.

The highest 8-hour TWA reading, 3,059 μg/m³, was obtained for a worker using a pneumatic-powered needle gun equipped with a contractor-built water-spray system to remove epoxy surfacer from an indoor concrete block wall. Although the water-spray system dripped a trickle of water on the wall surface and eliminated visible dust from the operation, the result indicates the ineffectiveness of this particular wet method in controlling respirable quartz exposure (NIOSH, 1983).

Results at the low end of the range (13 readings were reported as less than or equal to 25 μg/m³) are attributable in part to the fact that some workers drilled for significantly less than 8 hours per shift. For example, in two of the readings reported as less than or equal to the LOD of 12 μg/m³, the sampled workers each drilled concrete for 90 minutes out of their 8-hour shifts (OSHA SEP Inspection Report 300460243). On the other hand, one of the lowest results (below the LOD of 17 μg/m³) was obtained for a worker who jackhammered on a concrete bridge during a 345-minute period. A water hose was used to continuously wet the work area at the breaking point (OSHA SEP Inspection Report 106719750). In another study of jackhammering operations, samples obtained for 21 workers jackhammering concrete outdoors and using compressed air lances for cleaning produced a median respirable quartz concentration of 269 μg/m³ (range ≤12 μg/m³ to 624 μg/m³, mean 286 μg/m³) (NJDHSS, 2000). The use of compressed air for cleaning likely contributed to these exposure levels.

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[12]Sources of exposure monitoring data: OSHA SEP Inspection Reports 106719750, 109878371, 113451975, 116194440, 122121270, 300033461, 300440054, 300440096, 300460243, 300522869, 300522992, 300589421/L2809, 301454922, 301456703, 302002423, 302003694, 302005632; Shields, 1999, 2000; NJDHSS, 2000; NIOSH, 1983, 1992a, 1992b; NIOSH ECTB 233-105c, 1999; NIOSH ECTB 233-111c, 1999; NIOSH ECTB 233-120c, 1999; NIOSH ECTB 233-121c, 1999.

Another of the highest readings for impact drillers, 2,350 $\mu g/m^3$, was obtained for a worker inside a parking garage helix with no engineering controls in place, chipping concrete with an air hammer during a 418-minute period (NIOSH, 1999a). By contrast, using water before jackhammering indoors resulted in lower readings for four workers (sample durations ranged from 432 to 452 minutes); the respirable quartz concentrations in these samples ranged from 99 $\mu g/m^3$ to 236 $\mu g/m^3$ (OSHA SEP Inspection Report 302002423). Although the workers wetted the concrete before jackhammering, they did not re-apply water after breaking the surfaces. The inspection report noted that a fan rigged with filters was ineffective because it was too small for the room. It also indicated that cooling fans aimed toward the employees were ineffective in controlling exposures (OSHA SEP Inspection Report 302002423).

NIOSH obtained two samples for workers chipping plaster and concrete indoors using chip hammers during a 483-minute period and found PBZ respirable quartz concentrations of 130 $\mu g/m^3$ and 150 $\mu g/m^3$. Each worker spent 60 percent of the shift operating a chip hammer and 10 percent of the shift cleaning the debris with a water sprayer. NIOSH determined that a site-built LEV system was ineffective in controlling respirable quartz exposures. The air intake was not close enough to the point of dust generation, and the cardboard filter enclosure was not framed or gasketed to prevent leaks. Also, at the end of the shift, the workers vigorously shook the LEV system filters over a large trash receptacle to clean them, a likely source of further respirable quartz exposure (NIOSH, 1999b).

3.7.3 Impact Drillers: Technological Feasibility—Baseline Controls

Based on a review of OSHA, NIOSH, and other published and unpublished sources, ERG concludes that baseline controls for impact drillers working outdoors involve dry impact drilling on concrete, with no engineering controls or dust-suppressing work practice controls. ERG's data show that impact drillers working indoors often attempt various methods of dust control, but no single method is used consistently.

Of the 100 sample results for impact drillers summarized in the exposure profile (see Tables 3-1 and 3-2), ERG identified 37 results for impact drillers working outdoors with baseline controls. For this group, the median 8-hour TWA PBZ respirable quartz concentration was 98 $\mu g/m^3$, and the mean concentration was 162 $\mu g/m^3$. These results were obtained for workers at 17 different sites.[13]

The remaining 63 readings were obtained for impact drillers working either indoors or outdoors with various controls in place, or for whom no information is available regarding controls or working conditions.[14]

NIOSH obtained 8-hour TWA respirable silica results of 297 and 449 $\mu g/m^3$ for two impact drillers working under baseline conditions (NIOSH ECTB 233-121c, 1999). The workers stood on an outdoor scaffold and chipped the edge of a parking garage slab during the entire 450-minute sampling period. The 8-hour TWA results tend to be lower for workers who spend less than their full shifts breaking concrete. For example, a respirable quartz concentration of 784 $\mu g/m^3$ was obtained for the 30-minute period in which a worker operated a jackhammer under baseline conditions. NIOSH reported that the worker had no other silica exposure during the shift and calculated an 8-hour TWA of 49 $\mu g/m^3$ (NIOSH, 1992a).

3.7.4 Impact Drillers: Technological Feasibility—Additional Controls

Wet drilling and using tools equipped with LEV are the primary additional controls available to reduce the respirable quartz exposures of impact drillers. The effectiveness and availability of these measures are discussed in the following paragraphs.

Although ERG was not able to identify a commercial source of impact drills equipped with water supply systems, impact drillers have devised methods for introducing water during drilling. One method is to apply water by using a garden and/or hydraulic hose taped to the tool's bit. In one instance (discussed

[13]Exposure monitoring data sources: OSHA SEP Inspection Reports 113451975, 122121270, 300033461, 300440054, 300440096, 300460243, 300522869, 300522992, 300589421/L2809, 301456703, 302005632; NJDHSS, 2000; NIOSH, 1992a; NIOSH ECTB 233-121c, 1999; Shields, 2000.

[14]Exposure monitoring data sources: OSHA SEP Inspection Reports 109878371, 113451975, 122121270, 300295953, 300440054, 300440096, 300522869, 300522992, 302003694, 302005632,; NIOSH, 1983, 1992a, 1992b; NIOSH ECTB 233-105c, 1999; NIOSH ECTB 233-111c, 1999; NIOSH ECTB 233-121c, 1999; NJDHSS, 1999; Shields, 2000.

above in the exposure profile), a continuous stream of water directed at the concrete breaking point during a 345-minute period resulted in a respirable quartz exposure level below the LOD of approximately 17 $\mu g/m^3$. This reading was obtained for a jackhammer operator breaking concrete outdoors (OSHA SEP Inspection Report 106719750), and represents an 83 percent reduction from the baseline median exposure level of 98 $\mu g/m^3$.

Zalk (2000) evaluated a prototype water-supplying jackhammer as part of a pilot study and found that the water-supplying tool reduced quartz exposures significantly compared with dry jackhammering. The median reading obtained for two 90-pound jackhammer operators (two samples per operator) performing impact drilling outside in dry conditions was 300 $\mu g/m^3$, compared with a median of less than or equal to the LOD of 70 $\mu g/m^3$ obtained during wet jackhammering. This is an exposure reduction of at least 77 percent. Exposure was reduced by 98 percent for workers performing wet jackhammering indoors in dry conditions. The median respirable quartz reading went from 1,300 $\mu g/m^3$ in dry conditions to 30 $\mu g/m^3$ for wet methods. None of the results associated with wet methods (indoors or outdoors) exceeded 100 $\mu g/m^3$. Noted that, for the purpose of evaluating exposure with and without the control, these readings represent actual sampling times (rather than calculated 8-hour TWAs). They were based on short sample durations ranging from 54 to 186 minutes, during which the workers used jackhammers continuously (Zalk, 2001).

NIOSH (2003—PHB 282-11a) investigated a similar water spray dust control used by workers breaking concrete with 60- and 90-pound jackhammers. Using both a direct reading instrument and a high-flow cyclone and filter, NIOSH collected 10-minute readings with and without the spray activated. Compared to concentrations during uncontrolled pavement breaking, PBZ respirable dust concentrations were between 72 and 90 percent lower when the water spray was used. The flow rate of 350 milliliters per minute reportedly dried quickly, without adding a substantial amount of water to the work site (NIOSH EPHB 282-11a, 2003). Sam and Williams (2000) also reported that a water spray nozzle mounted on a hand-held pneumatic chipper decreased respirable dust approximately 70 percent in the worker's breathing zone.

Impact drillers working during subfreezing conditions—like earth drillers and grinders—might need to add an environmentally acceptable antifreezing agent to the water supply, assuming that any staining caused by the agent will not cause the product to be rejected. Propylene glycol is an environmentally acceptable antifreeze (ATSDR, 1999).

LEV systems present an additional control option for reducing the respirable quartz exposures of impact drillers. In the study described above, NIOSH also tested two tool-mounted LEV shrouds: one custom built, the other a commercially available model. Comparing multiple short term-samples, NIOSH found that the shrouds reduced PBZ respirable dust by 48 to 60 percent (NIOSH EPHB 282-11a, 2003). In a separate evaluation, NIOSH showed that this type of LEV system controls dust equally well for smaller chipping equipment. That evaluation involved short-term PBZ samples taken while workers used 25- or 30-pound jackhammers to chip concrete from inside concrete mixer truck drums. During 90- to 120-minute periods of active chipping, mean respirable silica levels decreased 69 percent (from 970 to 300 $\mu g/m^3$) when the workers used a tool-mounted LEV shroud in these enclosed spaces (NIOSH EPHB 247-19, 2001). In this study, a combination of LEV and general exhaust ventilation provided additional dust control, resulting in a 78 percent decrease in respirable silica readings. Respirable dust levels decreased by a slightly smaller amount (54 percent) due to a lower percentage of silica in samples associated with shroud use.

Some impact drill manufacturers currently offer LEV options (Atlas-Copco, 2001; Krenzer, 2000; Trelawny, 2001; Shave-Away, Europe, 2001). Other companies specialize in manufacturing after-market ventilation systems for various hand-held tools (DustControl AB, 1999; Alto International A/S, 2001).

A combination of LEV and water is another possible control option, although ERG has not been able to quantify its effectiveness. Information obtained for workers operating hand-held grinders suggests that combining wet methods and LEV might reduce exposure further, in the range of 7 percent beyond using wet methods alone (NIOSH, 1998; NIOSH ECTB 247-12, 2000). Thus, ERG estimates that the combined benefit could offer an exposure reduction of approximately 84 percent compared to uncontrolled impact drilling.

Worker positioning upwind of the dust generation point might also be effective for reducing exposure in some cases. Due to variability of wind conditions, however, ERG believes it is unlikely that this practice could reliably and routinely control the respirable quartz exposures of impact drillers.

3.7.5 Impact Drillers: Technological Feasibility—Conclusion

Based on the information presented above, ERG concludes that using wet methods, combined with low-dust cleaning methods, controls the respirable quartz exposures of most impact drillers to a level equal to or less than 100 $\mu g/m^3$. This conclusion is based on the findings of Zalk (2000). Additionally, in the case of two impact drillers who spent 450 minutes chipping concrete under baseline conditions (8-hour TWAs equal to 297 and 449 $\mu g/m^3$), a 77 percent decrease in exposure due to wet methods would have resulted in levels of 68 and 103 $\mu g/m^3$. Because most impact drillers work at the task less than 7 hours per day, most will achieve exposure levels below 100 $\mu g/m^3$. Additionally, ERG expects that many impact drillers could reduce their exposure further by using vacuum rather than blowing methods to clean work surfaces.

Zalk (2000) showed that wet methods can be as effective indoors as outdoors: levels were 100 $\mu g/m^3$ or less under both conditions. Wet methods are mainly applicable, though, during outdoor operations in temperatures above freezing. Water might not be an exposure control option for workers performing indoor renovation projects, especially where adjoining or neighboring suites are still occupied. Based on information from the inventor of a water-fed jackhammer, ERG estimates that 80 percent of impact drilling operations can be controlled using properly designed and applied wet methods (Zalk, 2001).

The use of LEV-equipped tools is another option for controlling the respirable quartz exposures of impact drillers, but experimental data suggest that the tool-mounted shrouds currently available for chipping equipment are somewhat less effective than wet methods. For the two outdoor chipper operators described above, the 69 percent exposure reduction offered by LEV would result in full shift exposure levels of 86 and 139 $\mu g/m^3$. Respiratory protection would be required to adequately protect some workers.

A combination of LEV and water is another possible control option. As noted previously, data for workers operating hand-held grinders suggests that combining wet methods and LEV might reduce exposure further (NIOSH, 1998; NIOSH ECTB 247-12, 2000). Thus, ERG estimates that the combined benefit could offer an exposure reduction of approximately 84 percent compared to uncontrolled impact drilling. In the previous paragraph's example, a combination of LEV and wet methods might have decreased the result of 449 $\mu g/m^3$ to 72 $\mu g/m^3$.

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3.8 MASONRY CUTTERS USING STATIONARY SAWS

3.8.1 Stationary Masonry Cutters: Process Description

Many construction workers use stationary saws to cut silica-containing masonry materials, such as bricks, concrete blocks, stone, and tile. The saws, which can be electric or gasoline-powered, are used to make straight or mitered cuts. Each saw has a blade, mounted either to an arm that moves down onto the work or to a fixed table with the work moving over the blade. In either configuration, the masonry is brought to the saw, and the saw's orientation is fixed. The cutting surface is generally about waist-high (OSHA SEP Inspection Report 300444676; NIOSH, 1996). (This report discusses masonry cutters who use portable saws under a separate job category.)

Many saw operators alternate cutting with laying masonry and/or mixing mortar, and thus might cut for only a short portion of the shift (OSHA SEP Inspection Report 300646510; NIOSH ECTB 233-118c, 1999). For example, a general contractor supervising masonry work for a 21,000-square-foot addition to a local government building stated that cutting "rarely exceeds two to three hours per workday" (Yereb, 2003). Some saw operators, however, cut masonry nearly continuously throughout the shift (OSHA SEP Inspection Report 122316805).

3.8.2 Stationary Masonry Cutters: Exposure Profile

As Table 3-1 indicates, the full-shift PBZ respirable quartz readings for masonry cutters using stationary saws range from 12 $\mu g/m^3$ or below to 2,005 $\mu g/m^3$, with a median of 63 $\mu g/m^3$ and a mean of 230 $\mu g/m^3$.[15] These results were obtained from 13 construction sites.

Of the 28 readings for workers in this job category, 6 (about 21 percent) are less than or equal to 25 $\mu g/m^3$, as Table 3-2 shows. Four of these six readings were for workers who cut for only a small part of

[15]Sources of exposure monitoring data: ERG, 2000; Lofgren, 1993; NIOSH ECTB 233-116c, 1999; NIOSH ECTB 233-118c, 1999; Minnesota OSHA MN-302501929, 2000; OSHA SEP Inspection Reports 113451538, 122316805, 122317480, 300444676, 300628344, 300646510, 302007034, 302547278; Shields, 2000.

their shifts. For example, two readings reported as less than or equal to the LOD of 12 $\mu g/m^3$ were obtained for workers who performed dry cutting of concrete block or brick for 15 percent of their shifts (approximately 75 minutes) or less; they spent the remainder of their shifts performing tasks that did not generate significant dust (NIOSH ECTB 233-116c, 1999; NIOSH ECTB 233-118c, 1999). Another worker with a reading less than or equal to the LOD was laying tile and cut just a few ceramic tiles, sometimes using a wet saw (ERG, 2000). A result of 21 $\mu g/m^3$ was obtained for a worker who performed dry cutting for only about 47 minutes throughout a shift (NIOSH ECTB 233-118c, 1999). The other low readings were obtained for a worker who cut inside a ventilated box for about 15 percent of a shift (OSHA SEP Inspection Report 302007034) and a worker who was wet cutting firebricks throughout a shift (OSHA SEP Inspection Report 113451538).

Not all masonry cutters who cut for only small parts of their shifts, however, are exposed to such low levels of respirable quartz. For example, a full-shift 8-hour TWA of 852 $\mu g/m^3$ was obtained for a worker who cut for only 56 minutes during the shift (Lofgren, 1993). Although this worker was cutting masonry outdoors, he was working against a wall that might have hindered dust dispersal. A reading of 292 $\mu g/m^3$ was obtained for a worker dry-cutting concrete block for 30 percent of the shift (approximately 144 minutes) (NIOSH ECTB 233-118c, 1999). The highest 8-hour TWA respirable quartz concentration, 2,005 $\mu g/m^3$, was recorded for a sawyer cutting blocks with dry methods throughout a shift (OSHA SEP Inspection Report 122316805). These data indicate that the respirable quartz concentrations and the durations of actual exposure vary widely for workers in this job category.

3.8.3 Stationary Masonry Cutters: Technological Feasibility—Baseline Controls

Based on a review of OSHA, NIOSH, and other published and unpublished reports, ERG has determined that baseline conditions for masonry cutters using stationary saws include dry cutting outdoors with no engineering controls or dust-suppressing work practice controls. While most masonry saws can be operated using wet methods, the data contained in the industry profile suggest that these saws are frequently operated without active water flow.

The exposure monitoring data representing baseline conditions show a wide range of respirable quartz concentrations and exposure durations. Of the 28 full-shift PBZ readings summarized above in the exposure profile, ERG identified 12 readings for workers cutting outdoors at baseline conditions.[16] Those 12 readings range from less than or equal to the LOD of 12 μg/m³ (only one reading) to 2,005 μg/m³, with a median of 50 μg/m³ and a mean of 354 μg/m³. The single LOD reading was obtained for a worker dry-cutting concrete block for approximately 47 minutes of the 471-minute sampling period (NIOSH ECTB 233-118c, 1999). The highest 8-hour TWA respirable quartz concentration was recorded for a sawyer cutting concrete blocks with dry methods throughout a shift (OSHA SEP Inspection Report 122316805).

ERG has no examples of cutters working indoors at baseline conditions; all such workers employed either wet methods or LEV.

3.8.4 Stationary Masonry Cutters: Technological Feasibility—Additional Controls

The primary exposure controls available for masonry cutters using stationary saws are wet sawing methods, LEV-equipped saws, and LEV at the cutting operation. The following paragraphs discuss the effectiveness and availability of these methods.

ERG identified seven full-shift PBZ respirable quartz results for masonry sawyers using wet methods. These ranged from the LOD of 12 μg/m³ to 93 μg/m³, with a median of 33 μg/m³ and a mean of 42 μg/m³ (NIOSH ECTB 233-116c, 1999; NIOSH ECTB 233-118c, 1999; OSHA SEP Inspection Report 113451538; Shields, 2000). This median is slightly lower than the median baseline exposure reading of 50 μg/m³. The mean associated with wet cutting is substantially lower than the baseline (dry cutting) mean of 354 μg/m³. The available exposure monitoring data, however, include examples of elevated exposure even with wet cutting methods. For example, a reading of 80 μg/m³ was obtained for a sawyer wet-cutting concrete brick and block for only 20 percent of a shift (about 96 minutes) (NIOSH ECTB 233-118c, 1999). NIOSH observed that a significant dust cloud was generated during cutting, indicating that the wetting was not sufficient to provide significant exposure control.

Yereb (2003) obtained similar results for water-fed masonry saws used to cut concrete block at an outdoor construction site. During two 1-hour periods of wet cutting, the PBZ respirable silica level was 87

[16]OSHA SEP Inspection Reports 122316805, 122317480, 300444676, 300628344, 300646510, 302547278; Lofgren, 1993; Minnesota OSHA MN-302501929, 2000; NIOSH ECTB 233-118c, 1999.

$\mu g/m^3$ for one sample and below the LOD for the other. Due to the short sample duration, the LOD for quartz was 77 $\mu g/m^3$. In contrast, PBZ respirable silica levels during dry cutting ranged from 3,000 to 15,000 $\mu g/m^3$ during 10-minute periods of active sawing. These results suggest that one can reduce even the highest exposures to 50 to 100 $\mu g/m^3$ by switching to wet methods. The investigator concluded, however, that "wet cutting substantially reduces worker exposures to silica dust, but does not entirely eliminate them."

ERG identified several commercial sources of water-fed stationary saws, including EDCO and Target (Chrisinger, 2001). Such a saw has a water basin with a pump that recycles the water from the catch basin through hoses and over the blade and masonry unit being cut. According to NIOSH (ECTB 233-118c, 1999), a wet-cut saw costs $500 to $2,000 more than a comparable dry-cut saw, depending on whether the model is purchased as a wet-cut saw or retrofitted for wet-cutting by the contractor. A wet saw needs a source of water, and those with water filtration systems require more maintenance and servicing than dry-cut saws because of clogging of hoses and filters. Also, Yereb (2003) noted that worn saw blades should be replaced to minimize the amount of fine particles produced. Wet-cut saw blades are similar in price to dry-cut blades and might last longer. Dry- and wet-cut blades are functionally interchangeable, but each blade type can only be used under the intended wet or dry cutting conditions.

For masonry cutters working during subfreezing conditions (as for other workers mentioned in previous sections), it might be possible to add an environmentally acceptable antifreezing agent to the water supply, assuming that any staining caused by the agent will not cause the product to be rejected. Propylene glycol is an environmentally acceptable antifreeze (ATSDR, 1999). ERG was not able to quantify the effectiveness of this method in reducing exposure.

The use of LEV-equipped stationary masonry saws is another engineering control option. However, the available exposure monitoring data provide only limited information about the effectiveness of this option. Three full-shift PBZ results—91 $\mu g/m^3$, 316 $\mu g/m^3$, and 824 $\mu g/m^3$—were obtained for workers using LEV-equipped stationary saws indoors (OSHA SEP Inspection Report 302547278). The source of those results provides no further information on the working conditions, work practices, or saw designs involved. Therefore ERG considers these data of limited usefulness in characterizing the effectiveness of LEV-equipped saws.

ERG has also reviewed experimental data on the effectiveness of LEV-equipped stationary saws in controlling PBZ respirable quartz. Croteau (2000) evaluated an LEV system installed on a stationary saw, comparing the LEV's system effectiveness at reducing airborne respirable quartz levels at two different flow rates and with operating without the LEV. For the purpose of evaluating exposure with and without the controls, these readings represent actual sampling times (rather than calculated 8-hour TWAs).

For Croteau's brick-cutting experiment, three 15-minute samples were taken while the LEV system was not functioning (0 CFM) and when the LEV was operating at 30 CFM; two 15-minute samples and one 9-minute sample were taken at 70 CFM. At the lower air flow rate, exposure was 80 percent lower than when the same saw was used to cut bricks without the LEV (medians of 1,140 $\mu g/m^3$ versus 5,630 $\mu g/m^3$). Sawing bricks at the higher air flow rate lowered exposure 86 percent (median 790 $\mu g/m^3$). Croteau conducted the same tests when the stationary saw was used to cut paver blocks. Six 15-minute samples were taken at all three flow rates. Exposure was reduced 84 percent at 30 CFM (median of 3,520 $\mu g/m^3$ versus 21,460 $\mu g/m^3$) and 96 percent at 70 CFM (median 935 $\mu g/m^3$).

At least one manufacturer currently offers LEV options for stationary saws. A masonry saw designed to be used with either LEV or wet methods (or both) is also commercially available (Chrisinger, 2001). While this combined approach has not been tested for masonry saws, wet methods used with LEV reduced earth drillers' respirable dust exposure by 42 percent compared to wet methods alone (Zimmer, 1997). Information obtained for workers operating hand-held grinders suggests that a combination of wet methods and LEV might reduce exposure in the range of 7 percent beyond wet methods alone (NIOSH, 1998; NIOSH ECTB 247-12, 2000).

Although the Croteau data indicate that LEV can reduce exposure significantly, the data are of limited application in the current analysis, primarily because the exposure levels remain significantly elevated. There are no reliable data or studies indicating that the percentages of exposure reduction achieved in this study apply at lower levels of respirable quartz—such as the baseline median of 50 $\mu g/m^3$ or the mean of 354 $\mu g/m^3$.

Installing LEV next to cutting operations is another engineering control option. Four PBZ samples were obtained for workers who cut blocks in site-built ventilation booths throughout their shifts. When these booths located indoors, 8-hour TWA exposures were 15 and 93 $\mu g/m^3$. When they were located outdoors, exposures were 70 and 86 $\mu g/m^3$ (OSHA SEP Inspection Reports 302001409, 302007034). The booths were made of plywood (6 feet by 6.5 feet by 3.5 feet), each with a 36-inch fan. OSHA measured an airflow of 250 feet per minute (FPM) across the fans' faces, which is consistent with ACGIH's recommendation for an abrasive cut-off saw booth. Designs for a movable hood and saw enclosures are provided in the ACGIH *Industrial Ventilation* manual (2001).

3.8.5 Stationary Masonry Cutters: Technological Feasibility—Conclusion

ERG concludes that by using wet cutting methods, most masonry cutters can achieve full-shift PBZ respirable quartz levels below 50 $\mu g/m^3$. This conclusion is based on the median 8-hour TWA reading of 33 $\mu g/m^3$ for workers who used wet methods to cut masonry with stationary saws. Additionally, although Yereb (2003) reported results as high as 90 $\mu g/m^3$ during a 1-hour period of active wet cutting, most masonry cutters operate saws intermittently rather than constantly for 8 hours. ERG's conclusion also presumes that saw blades will be replaced when warn and wet methods will be accompanied by rigorous housekeeping to prevent dust particles from becoming airborne when dust-laden water dries.

ERG concludes that using LEV-equipped stationary saws, as opposed to using no form of dust control, might reduce the full-shift PBZ respirable quartz exposures of some masonry cutters. ERG cannot state, however, that this method reliably reduces exposures to levels below 100 $\mu g/m^3$.

As an alternative, most masonry cutters who use LEV saw enclosures designed to meet ACGIH-recommended criteria might achieve full-shift respirable silica levels less than 100 $\mu g/m^3$. The four 8-hour TWA results obtained for workers using this control were below that value (OSHA SEP Inspection Reports 302001409, 302007034). This method appears to be beneficial both indoors and out, as long as the booth air is exhausted outdoors. Further reductions might be achieved through improved work practices and design modifications (for example, configuring the booth to exhaust the dust plume before it can disperse within the booth).

ERG presumes that a combination of controls will reduce exposures to levels below 100 $\mu g/m^3$ for masonry cutters who continue to experience elevated exposures after adopting wet methods, LEV, or ventilated booths. For example, positioning a wet-saw in a ventilated booth would prevent dust-laden mist from spreading airborne particulates through the workplace as it dries. This combined approach would also make it possible to use wet methods in indoor locations where mist might otherwise complicate their use.

Alternatively, masonry saws that combine wet methods with LEV capability are commercially available (EDCO, 1999). Although this combination has not been tested for masonry cutters, results obtained for other construction tasks suggest that a combination of wet methods and LEV offers an additional benefit over either method alone.

According to the minutes of the Seventh CPWR/NIOSH Engineering and Work Practice Controls Work Group (1999), Eileen Betit of the Bricklayers Union reported that three 1998 agreements in Massachusetts and Michigan included collective bargaining language eliminating or severely restricting dry cutting of masonry products without ventilation or water. This suggests that the use of water and LEV for masonry cutting is becoming an accepted industry practice.

3.8.6 Stationary Masonry Cutters: References

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3.9 MASONRY CUTTERS USING PORTABLE OR MOBILE SAWS (HAND-HELD CIRCULAR, WALK-BEHIND, AND/OR DRIVEABLE SAWS)

3.9.1 Masonry Cutters Using Portable or Mobile Saws: Process Description

Masonry cutters use a variety of portable or mobile saws, including hand-held, walk-behind, and driveable saws, to perform a wide range of cutting activities. The activities include cutting segments out of existing masonry structures or pavement, cutting straight lines (e.g., to straighten an edge or to weaken a structure in preparation for demolition), and cutting grooves for utility installation.

The **hand-held saw** operator holds the saw with both hands by the handles at the top and/or back of the housing. The blade of the saw is generally 12 to 18 inches in diameter and makes cuts up to about 7 inches deep. Most operations are performed at waist or ground level, and the cutter usually leans over the work to guide the blade properly and gain a better view of the work (OSHA SEP Inspection Reports 122376791, 300444676; NIOSH, 1996). This often puts the cutter's breathing zone near the point of dust generation.

Operators typically use hand-held saws for brief, intermittent periods, for example to cut a concrete curb or saw a small number of bricks. This process, however, might be repeated numerous times over the course of a shift. Between cuts, workers generally perform tasks related to the purpose of the cut. Some of these tasks can contribute to an individual's overall respirable silica exposure level, particularly when the worker performs chipping, grinding, or demolition.

A saw might be mounted on a wall, allowing the operator to make successively deeper cuts at the same point by using increasingly larger blades. For this application, the operator is typically within arm length of the blade, as with hand-held saws.

Walk-behind saws are used to cut expansion joints or slabs out of existing pavement. Depending on the size of equipment, the walk-behind saw operator either maneuvers the equipment using bars mounted to the back of the saw or uses a handle to operate the equipment in a manner similar to pushing a lawn mower. Some workers, however, lean over or around saws to better see their cut lines. This reduces the distance between a worker's breathing zone and the cutting blade. Walk-behind saws, which can be used indoors or outdoors, often include water-feed mechanisms to cool their blades. Either the municipal water system or a portable tank can serve as the water source.

A **driveable saw** operator typically sits in an open cab about 15 feet away from the point of operation (Shields, 1999). A driveable concrete cutter—sometimes called by a popular brand name, the Vermeer saw—is used to make long cuts (for instance, for utility installation). The blade housed by this vehicle can be 8 feet in diameter and 2 inches thick, and is typically equipped with a water-feed system to provide a coolant for the blade. Due to their size, driveable saws are typically used outdoors. Based on the sampling durations included in Shields (2000), ERG estimates that these saws typically operate for 1 to 2 hours per location and then are packed up and transported to other sites, possibly serving two sites per day.

3.9.2 Masonry Cutters Using Portable or Mobile Saws: Exposure Profile

As Table 3-1 shows, the 74 full-shift PBZ respirable quartz readings for masonry cutters using portable or mobile saws range from less than or equal to the LOD of 11 $\mu g/m^3$ to 10,318 $\mu g/m^3$, with a median of 65 $\mu g/m^3$ and a mean of 312 $\mu g/m^3$.[17] The following discussion addresses hand-held saws, walk-behind saws, and driveable saws separately.

The 49 results associated with **hand-held saws** are spread over a wider range than the results for other saw types, including values from less than or equal to the LOD of 12 up to 10,318 $\mu g/m^3$. The median result for this group is 102 $\mu g/m^3$ and the median is 429 $\mu g/m^3$ About 55 percent of the readings (27 of 49) are greater than 100 $\mu g/m^3$, as Table 3-2 shows. The highest full-shift PBZ respirable quartz reading, 10,318 $\mu g/m^3$, was recorded for a plumber who used a hand-held saw to dry-cut slabs out of concrete floors indoors; a floor-stand fan aimed at an open window was the only attempt at dust control (NIOSH, 1992).

[17]Sources of exposure monitoring data: Lofgren, 1993; Minnesota OSHA Inspection Reports 302501929, 302502505; NJDHSS, 2000; NIOSH, 1992, 1993, 1995, 1996; NIOSH ECTB 233-115c, 1999; NIOSH ECTB 233-117c, 1999; NIOSH ECTB 233-118c, 1999; NIOSH ECTB 233-121c, 1999; OSHA SEP Inspection Reports 103011748, 113455141, 113463996, 122376791, 300219979, 300591047/L2809, 302003694; Shields, 2000.

As further shown in Table 3-2, 20 out of 49 readings (about 41 percent) were reported as less than or equal to 25 $\mu g/m^3$. Of these, 13 results were reported as less than or equal to the LOD of approximately 12 $\mu g/m^3$. Among the LOD readings, most were obtained for workers performing actual cutting operations for significantly less than 8 hours. For example, one full-shift LOD reading was obtained for a hand-held saw operator dry-cutting concrete pavement for 140 minutes (Shields, 2000). Similarly, another full-shift LOD reading was obtained for a portable saw operator wet-cutting concrete block for a 68-minute period. Another low reading, 21 $\mu g/m^3$, was obtained for a portable saw operator wet-cutting concrete floors indoors for about 40 percent (160 minutes) of a 401-minute shift (OSHA SEP Inspection Report 103011748). In all three cases, the calculated full-shift reading is based on the assumption that the worker had zero exposure for the unsampled portion of the shift.

The median level of 39 $\mu g/m^3$ observed for 22 operators using **walk-behind saws** is substantially lower than that associated with the workers using hand-held saws.[18] The range is also lower, from less than or equal to 11 $\mu g/m^3$ (the LOD) to 461 $\mu g/m^3$, with a mean of 108 $\mu g/m^3$.

Two LOD readings (again, 11 $\mu g/m^3$ or lower) were obtained for operators of walk-behind saws cutting highway expansion joints using wet methods, in 545-minute samples, despite bulk sample results indicating the presence of quartz in amounts of 18 percent to 24 percent (NIOSH, 1993). In another result obtained for a walk-behind saw operator, a full-shift reading of 461 $\mu g/m^3$ was recorded for an operator dry-cutting boundaries of repair areas of bridge deck; no engineering controls were in place (NJDHSS, 2000).

Three readings represent the full-shift PBZ respirable quartz exposures of **driveable saw** operators. One of the 8-hour TWA results reported for a Vermeer saw operator was less than or equal to the LOD of 12 $\mu g/m^3$, due to low respirable dust loading on the filter during the 70-minute sample period (Shields, 2000). Another 8-hour TWA reading obtained for a Vermeer saw operator, 33 $\mu g/m^3$, was based on a 125-minute sample that recorded a respirable quartz concentration of 128 $\mu g/m^3$ (Shields, 2000). As with other short-term readings, ERG calculated the full-shift result based on the assumption that the worker had zero exposure for the unsampled portion of the shift. The short-term result, however, indicates the

[18]NIOSH, 1995; NIOSH, 1993; Flanagan et al., 2001; Shields, 1999; Shields, 2000.

potential for elevated exposure if the worker were to operate the saw continuously over the entire 8-hour shift. Additionally, ERG estimates that some workers might continue cutting after moving the saw to another work site, so these results might under-represent operators' actual respirable silica exposure. Actual 8-hour TWAs could be 50 to 200 percent higher.

A third 8-hour TWA reading for a Vermeer saw operator, 88 $\mu g/m^3$, is based on an 80-minute sample that recorded a respirable quartz concentration of 530 $\mu g/m^3$. During the sampling period it was noted that the water discharge onto the saw was clogged, suggesting that the water supply was not effective in controlling airborne dust (Shields, 2000). This result demonstrates both the importance of equipment maintenance and the potential extent of exposure when dust control equipment is not functioning properly.

3.9.3 Masonry Cutters Using Portable or Mobile Saws: Technological Feasibility--Baseline Controls

Baseline controls for masonry cutters using **hand-held saws** include work performed outdoors on concrete or masonry units, with no engineering controls or specific work practices in place. Of the 49 sample results for masonry cutters using hand-held saws, ERG identified 22 results for masonry cutters working at these baseline conditions, associated with a median 8-hour TWA PBZ respirable quartz concentration of 148 $\mu g/m^3$ and a mean concentration of 221 $\mu g/m^3$. These results were obtained for workers from 18 different sources.[19] Of the 22 results, 3 were reported as less than or equal to the LOD of 12 $\mu g/m^3$. As mentioned in the exposure profile, one full-shift LOD reading was obtained for a hand-held saw operator dry-cutting concrete pavement for 140 minutes (Shields, 2000). Another LOD reading was based on a 326-minute sample collected for a worker dry-cutting concrete block (Shields, 2000). The highest reading for this subcategory, 1,472 $\mu g/m^3$, was based on a 451-minute sample collected for a worker who spent 65 percent of the shift (about 300 minutes) dry-cutting concrete, and 10 percent (about 45 minutes) chipping concrete (NIOSH ECTB 233-121c, 1999).

Masonry cutters using **walk-behind saws** most commonly work outdoors cutting concrete roadways, using wet methods but no specified work practices. Of the 22 full-shift PBZ respirable quartz

[19]OSHA SEP Inspection Reports 122376791, 300591047/L2809; NIOSH, 1992; NIOSH ECTB 233-117c, 1999; NIOSH ECTB 233-118c, 1999; NIOSH ECTB 233-121c, 1999; NJDHSS, 2000; Shields, 2000.

results for masonry cutters using walk-behind saws, ERG identified 14 results associated with operators working at these baseline conditions. These results were obtained for workers from six sources, one of which represents multiple construction sites (NIOSH, 1993, 1995; Shields, 2000). At three of these sites, workers used a single wet method: spraying water at the breaking point of the pavement. In addition to spraying water at the breaking point , workers at a fourth site cut into "fresh" concrete, which had been poured within 6 hours of cutting. As described below, full-shift LOD readings were obtained for workers at this site (NIOSH, 1993).

Eight of the fourteen baseline results obtained for walk-behind saw operators were reported as less than or equal to the LOD of 12 $\mu g/m^3$. Four of the LOD readings were obtained at a single site evaluated by NIOSH, at which the workers cut concrete within 6 hours of pouring; water from a hose was also sprayed at the saw tip during the cutting (NIOSH, 1993). At that site, the highest quantifiable reading was 40 $\mu g/m^3$, obtained for a worker wet-cutting ½-inch grooves in a roadway. In separate study, NIOSH obtained an 8-hour TWA result of 61 $\mu g/m^3$ (the limit of quantification) for a worker cutting with water supplied to the saw tip during a 231-minute sampling period (NIOSH, 1995).

Baseline controls for **driveable saw** operators include cutting pavement outdoors using water-fed saws. The operator's distance from the point of operation is also a form of control: driveable saw operators typically work from open cabs about 15 feet away from the cutting operation. Two 8-hour TWA PBZ respirable quartz samples were obtained for workers driving saws under baseline conditions for 1 to 2 hours of the shift. As the exposure profile explains, one of the results was reported as less than or equal to the LOD of 12 $\mu g/m^3$ (actual sample duration 70 minutes) (Shields, 2000). The other 8-hour TWA reading, 33 $\mu g/m^3$, was based on a 125-minute sample that recorded a respirable quartz concentration of 128 $\mu g/m^3$ (Shields, 2000).

3.9.4 Masonry Cutters Using Portable or Mobile Saws: Technological Feasibility—Additional Controls

For **hand-held saw** operators, the primary additional exposure control options are water and LEV-equipped saws.

Of the 61 full-shift PBZ respirable quartz readings summarized for this job category in the exposure profile, ERG identified 8 for hand-held masonry saw operators at several sites using the additional control of wet cutting methods (Lofgren, 1993; Shields, 1999, 2000). The eight readings obtained for workers performing wet cutting ranged from less than or equal to 12 $\mu g/m^3$ to 101 $\mu g/m^3$, with a median of 24 $\mu g/m^3$.

Water-fed hand-held saws that are gas-powered, air-powered, and hydraulic-powered are commercially available (Stihl, 2001; Diamond Products, 2001; Partner Industrial Products, 2001). In an experimental study simulating workplace conditions, Thorpe et al. (1999) evaluated the effectiveness of water-fed hand-held saws in controlling respirable quartz. The study involved multiple 15-minute PBZ air samples collected while two test water-feed systems were turned on and off. Use of a hand-pressurized portable water supply reduced average respirable dust levels by up to 94 percent. The primary drawback of this system was that the tank required frequent re-pressurizing by hand. If pressure was allowed to fall, the water flow rate diminished and respirable dust concentrations rose. This system was most effective for short cuts that could be completed in a few minutes. Interestingly, the investigators noted that diamond blades cut faster than resin blades, allowing the saw operator to complete a longer cut before the portable tank pressure decreased.

When Thorpe et al. (1999) used the same procedure to evaluate a more constant water source (a hose connected to municipal supply system), the wet-cutting method decreased the mean respirable dust level by 96 percent relative to dry cutting. In this test of hand-held saws, the 15-minute PBZ samples collected during uncontrolled cutting on the same concrete slab indicated mean respirable crystalline silica concentrations of 1,700 to 4,800 $\mu g/m^3$ (multiple trials, cutting a concrete slab containing 40 percent silica). Other investigators have also reported respirable silica results in this range during periods of intensive cutting with hand-held saws (Shields, 2000; NIOSH, 1992, 1996; OSHA SEP Inspection Report 302003694; NJDHSS, 2000). As noted earlier, however, hand-held saws are typically used intermittently to make short cuts and 8-hour TWA values tend to be substantial lower.

Assuming that respirable quartz will also decrease by approximately 96 percent when wet methods are used, ERG calculates that the highest 8-hour TWA reading obtained for a worker dry cutting concrete outdoors, 1,472 $\mu g/m^3$, might be reduced to an estimated level of 60 $\mu g/m^3$ if the operator switched to a water-fed saw (NIOSH ECTB 233-121c, 1999). This assumes that the worker, who spent 65 percent of the shift dry-cutting concrete and 10 percent chipping concrete, controls the chipping activity to a similar level.

Uncontrolled exposure levels are generally higher indoors than outdoors, where natural air currents tend to dissipate dust. Nevertheless, in some cases, wet methods have performed at least as well indoors, reducing respirable dust and silica to the same levels achieved outdoors (Zalk, 2000). The research of Flanagan et al. (2001) suggests that this might not be the case for concrete cutting saws of any type. Operators and their assistants using water-fed walk-behind saws indoors encountered higher full-shift respirable silica levels (four results between 130 and 710 $\mu g/m^3$) than workers using similar water-fed saws outdoors (two results of 50 $\mu g/m^3$ or less). Furthermore, 8-hour TWA respirable quartz levels of 240 and 260 $\mu g/m^3$ were obtained for (1) a hand-held saw operator who used wet methods indoors and (2) an assistant using a wet shop vacuum to control the spread of slurry (Flanagan et al., 2001). Flanagan noted that "Since area and helper exposures are similar to the operator's exposure, the primary exposure might be due to a buildup of respirable aerosol within the enclosed space, rather than direct exposure to slurry spray. Judicious use of dilution ventilation with box fans and open doors and windows might reduce the exposure." There are several possible sources of airborne dust in this study, such as respirable aerosols released over time from mist spun off the water-fed saw blade (as opposed to direct exposure to the mist itself) and residual slurry left by the wet vacuum to dry on the floor. It is also important to note that vacuums, including wet vacuums, can produce airborne dusts through "reentrainment of already collected particles" (Trakumas et al., 2001). Factors such as decreasing airflow rate can decrease a vacuum's capture efficiency. Although vacuum exhaust air was not evaluated as a source of particle emissions in Flanagan et al. (2001), the wet vacs used by each pair of workers might have contributed to the respirable silica levels reported in the study.

ERG identified one other result, less than or equal to 21 $\mu g/m^3$ (the LOD), for a worker using wet methods and a hand-held saw indoors. In this case, a the worker spent 40 percent of a 401-minute monitoring period cutting a concrete floor.

It should be noted that accessories used to feed water to a hand-held saw sometimes include a cart, which functionally changes the saw from a hand-held model to a walk-behind model. Walk-behind saws are addressed in separate paragraphs below.

Hand-held saws can also be equipped with LEV air extraction systems. While ERG was not able to obtain extended-period exposure monitoring data indicating the effectiveness of LEV-equipped saws under workplace conditions, experimental data indicate that such saws might be somewhat effective in controlling respirable silica exposure. For example, using the same simulated workplace conditions described above, Thorpe et al. (1999) found that an LEV system on the hand-held saw reduced mean respirable concrete dust concentrations from 8.0 to 0.7 mg/m³, representing an 88 percent reduction in respirable dust exposure levels during periods of active cutting. Although saw-based LEV extraction equipment might also substantially reduce respirable silica results, ERG calculates that even an 88 percent reduction like the one measured in this controlled study would not necessarily reduce the respirable silica results of all hand-held saw operators to levels below the current PEL.

Nevertheless, results below the current PEL might be possible for workers using LEV-equipped hand-held saws intermittently, for example to cut bricks during masonry activities. NIOSH obtained 8-hour TWA respirable silica results between 117 and 388 μg/m³ for six workers at two separate construction sites (NIOSH ECTB 233-117, 1999; NIOSH ECTB 233-118, 1999). The workers used no dust controls while cutting brick or block for 20 to 40 percent of the 7- to 8-hour sampling periods; they worked outdoors or in partially sheltered areas. Based on the NIOSH reports, ERG suggests that these workers used the saw intermittently, spending a portion of the "cutting" time carrying and transferring masonry units to the designated saw area or moving the saw to positions where masonry units needed to be cut. They spent the rest of their shifts in activities unlikely to contribute substantial silica exposure (distributing mortar, setting rebar, operating cement vibrators, assisting bricklayers). If these workers switched to LEV-equipped saws that reduced dust levels at least 75 percent, the 8-hour TWA silica levels for all six of them might have been 97 μg/m³ or less.

ERG could not obtain information on the effectiveness of LEV-equipped saws used indoors. But the single result ERG obtained for uncontrolled cutting indoors—an 8-hour TWA of 10,320 μg/m³—is also the highest level reported for a worker operating a hand-held saw. This 350-minute sample was collected while a plumber cut the concrete floors around drains on each floor of a 16-story building. ERG estimates that, even if the worker had achieved the 88 percent dust reduction obtained under experimental conditions using the LEV dust control method (Thorpe et al., 1999), his exposure would still have exceeded 10 times the current PEL.

Unfortunately, LEV-equipped saws do not appear to offer a reliable level of dust reduction under all circumstances. In the laboratory, Croteau (2000) and Croteau et al. (2002) tested a hand-held saw equipped with an LEV system exhausted at 70 CFM, finding that this system did not reduce respirable silica exposure relative to the same saw without LEV. He concluded that the shape of the dust collection shroud opening allowed the rotating blade to push dust away from the shroud. Some saw and LEV combinations might require the rotation of the blade to be reversed to accommodate the shroud; the equipment manufacturer might charge a nominal fee for this service (USF Surface Preparation Group, 2002). The direction of blade rotation in the Croteau and Thorpe studies is unclear. Perhaps a reversal would have yielded lower exposure levels.

On the other hand, the LEV system evaluated by Thorpe was designed by the manufacturer for the specific model of saw tested, and included special features such as adaptations for left- or right-handed users as well as the depth of the cut. Therefore, ERG is uncertain whether the full exposure reductions seen in the Thorpe study could be achieved by all models of hand-held saws fitted with LEV. Note that, although Thorpe et al. conducted their study in the United Kingdom, manufacturers of the water-fed and LEV-equipped saws tested do offer equipment in the United States as well (Stihl, 2001; Hilti, 2003).

As noted above, at least one saw manufacturer offers an LEV system designed specifically for use with its saws. Other companies manufacture after-market ventilation systems for various hand-held tools (Shave-Away, Europe, 2001; Transmatic, 1999).

For **walk-behind saw** operators, the primary exposure control is to apply water directly to the breaking point during cutting, identified in the previous section as a baseline control associated with a median full-shift respirable quartz level of less than or equal to 12 $\mu g/m^3$ and a maximum level of 101 $\mu g/m^3$. When elevated exposure occurs during the use of wet methods, additional efforts might be taken to ensure that sufficient amounts of water are reaching the breaking point and that water-feed systems are working correctly (Minnesota OSHA Inspection Report 302502505; Shields, 2000). Workers might also need to ensure that all slurry (including that on clothing) is captured before it has a chance to dry. A walk-behind saw operator wet-cutting pavement considered dried particles released from work clothes to present the greatest source of dust exposure (Walk-Behind Saw Operator A, 2000).

Flanagan et al. demonstrated the importance of water flow rates in dust suppression. These investigators reported 8-hour respirable quartz levels as high as 350 $\mu g/m^3$ for a worker and assistant who spent 4 hours cutting concrete using a water-fed walk-behind saw and wet shop vac (to collect the slurry) at an indoor construction site (Flanagan et al., 2001). Water was supplied to the cutting blade at ½ gallon per minute. The 8-hour TWA dropped to 110 $\mu g/m^3$ when similar work was performed with a water-feed rate of 2 gallons per minute—but that level still exceeds the current PEL. As noted above, Flanagan suspected that exposure was due to a buildup of respirable aerosol within the enclosed space, rather than direct exposure to slurry spray. Several possible sources of airborne dust were present in the work spaces.

Water-fed walk-behind saws are commercially available and, reportedly, at least one manufacturer offers "an optional vacuum attachment to collect slurry" (Flanagan et al. 2001).

On some new construction projects, workers might achieve additional control by cutting recently poured concrete. As the "Baseline Controls" section describes, four full-shift LOD readings were obtained at a single site at which the workers cut concrete within 6 hours of pouring, while water was sprayed onto the breaking point (NIOSH, 1993).

The use of LEV-equipped walk-behind saws is another option. Although some manufacturers offer an LEV option for walk-behind saws (USF Surface Preparation Group, 2000b, 2002), ERG could not obtain exposure monitoring data on the effectiveness of LEV under either actual working conditions or experimental conditions.

For operators of **driveable saws,** the primary exposure control is the use of vehicles equipped with water-fed systems that apply water directly to the breaking point. The operator's distance from the point of operation is also a form of control, as mentioned above. As the "Baseline Controls" section describes, two 8-hour TWA PBZ respirable quartz readings are associated with these controls. One result was reported as less than or equal to the LOD of 12 $\mu g/m^3$ (actual sample duration 70 minutes), and the other result was reported as 33 $\mu g/m^3$ (actual sample duration 125 minutes) (Shields, 2000). The derived full-shift LOD readings are based on the assumption that the workers had zero exposure for the unsampled period of the shift. If, as ERG proposes in the "Exposure Profile" section, operators typically proceed to a second site, then their true 8-hour TWA exposure might be as much as twice as high as the values reported. In this case, for the two operators just described, average exposure for a shift could be up to 70 $\mu g/m^3$.

When elevated exposure occurs in this subcategory, maintenance on the water-feed system might result in additional control. The highest result in the driveable saw group, an 8-hour TWA PBZ respirable quartz exposure level of 88 $\mu g/m^3$, was obtained for a Vermeer saw operator who cut while the water nozzle at the saw blade was clogged (Shields, 2000). This value was based on an 80-minute sample with an actual respirable quartz reading of 530 $\mu g/m^3$ during the period monitored. Improvements to the water delivery system would likely have resulted in a lower exposure level, though follow-up sampling was not performed.

LEV-equipped driveable saws might be another option for controlling the exposures of operators of such saws. But, as mentioned above, ERG could neither identify sources for such equipment nor obtain exposure monitoring data indicating the effectiveness of LEV under either actual working conditions or experimental conditions.

For masonry cutters of all types working during subfreezing conditions—as for workers in similar categories—it might be possible to add an environmentally acceptable antifreezing agent to the water supply, assuming that any staining caused by the agent will not cause the product to be rejected. Ethylene glycol is an environmentally unsound choice, but propylene glycol could be a preferable antifreeze (ATSDR, 1999). ERG could not quantify the effectiveness of this method in reducing exposure.

3.9.5 Masonry Cutters Using Portable or Mobile Saws: Technological Feasibility—Conclusion

ERG concludes that the full-shift PBZ respirable quartz exposures of **hand-held saw** operators working *outdoors* might be reduced to 50 $\mu g/m^3$ or less through conscientious use of wet methods. This conclusion is based on the median full-shift reading of 24 $\mu g/m^3$ determined for hand-held saw operators using wet methods outdoors (applying water directly to the cutting point or using water-fed equipment).

When wet methods are not possible, ERG estimates that LEV might reduce full-shift PBZ exposures to levels in the range of 100 $\mu g/m^3$ in most cases when saws are used outdoors. The data are an inadequate basis, however, on which to determine whether outdoor workers using such saws can reliably achieve this level.

Both wet methods and LEV can help decrease the exposures of workers operating hand-held saws *indoors.* ERG concludes that employees who make just a few short cuts indoors over the course of their shifts (and have no other source of silica exposure) can achieve 8-hour TWA levels less than 100 $\mu g/m^3$ using either of these methods. With either wet methods or LEV equipment, however, 8-hour TWA results might still exceed the current PEL during shifts involving extended periods of indoor sawing. When working indoors, workers will likely need to use respiratory protection, for example half-facepiece respirators.

ERG's information suggests that the full-shift PBZ respirable quartz exposures of most **walk-behind saw** operators working *outdoors* are already controlled to a level less than or equal to 50 $\mu g/m^3$. The median result for 14 workers cutting (mainly concrete) under these baseline conditions is less than or equal to 12 $\mu g/m^3$, the LOD. Flanagan et al. (2001) also reported results of 50 $\mu g/m^3$ or less for walk-behind saw operators using wet methods. ERG concludes that the 7 percent (1 of 14) of walk-behind saw operators currently associated with exposures above this level can achieve results of 50 $\mu g/m^3$ or less through frequent, meticulous maintenance of water-feed systems (ensuring nozzles are cleaned or replaced as often as necessary to keep them functioning as intended) and sufficient use of water.

Walk-behind saw operators working *indoors* generally experience higher respirable silica results, yet ERG estimates that most of these workers can achieve levels of 100 $\mu g/m^3$ or less by using a combination of controls. The necessary control methods include use of sufficient wet methods (Flanagan et al. achieved 8-hour TWA results slightly greater than this level using 2.0 gallons per minute), meticulous maintenance of the water-feed system, rigorous control of slurry, a system for efficiently filtering or to discharge vacuum exhaust air outside the work space, and arrangements (for example, exhaust trunks) to improve fresh air exchange in enclosed areas. Although ERG could not obtain data on the effectiveness of these combined controls in this case, each of them has independently been shown to reduce airborne respirable dust concentrations for a variety of operations.

Alternatively, the exposure level of workers operating walk-behind saws indoors might be limited by a combination of wet methods (using meticulously maintained equipment) and respiratory protection, such as half-facepiece respirators.

ERG concludes that the 8-hour TWA PBZ respirable quartz exposures of most **driveable saw** operators are already less than 75 $\mu g/m^3$. ERG bases this conclusion on the median value of 33 $\mu g/m^3$ determined for this group, as well as ERG's estimate that driveable saw operators visit more than one site per day and thus might be subject to respirable silica exposure levels twice as high as those reported in the limited partial-shift data available to ERG. Furthermore, ERG proposes that the respirable silica levels of all driveable saw operators (even those cutting for several hours per shift) can be reduced to 50 $\mu g/m^3$ or less through frequent, meticulous maintenance of water-feed systems (as with walk-behind saw systems) and sufficient use of water. Operators of walk-behind saws are closer than driveable saw operators to the point where dust is generated, yet their median exposure level is less than or equal to 12 $\mu g/m^3$ when they use wet methods. ERG estimates that driveable saw operators can achieve a similar level, although their larger saw blades might need more water. The highest 8-hour TWA for a driveable saw operator (88 $\mu g/m^3$, obtained during an 80-minute sampling period) is associated with an upset in the water delivery system (Shields, 2000).

3.9.6 Masonry Cutters Using Portable or Mobile Saws: References

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3.10 MILLERS (USING PORTABLE OR MOBILE MACHINES TO WORK FIXED SURFACES)

3.10.1 Millers: Process Description

Millers grate or grind solid surfaces, such as concrete floors, masonry walls, sidewalks, and asphalt roads. Milling machinery often uses a rapidly rotating drum or a bit covered with nibs to abrade surfaces. Some milling machinery uses a shot-blast system. Smaller machines might instead contain several rotating abrasive cups. The operator guides smaller milling equipment by hand (hand-held or walk-behind tools, including scarifiers, are used for wall and floor work) or drives the larger models (e.g., road milling equipment user in recycling/resurfacing operations) from a seat on top. Smaller machines are operated by laborers or construction workers with specialties such as resurfacing, flooring, or electrical installation (i.e., creating grooves for conduit). Most milling equipment is operated dry, although a typical piece of asphalt road milling equipment has a water feed at the milling drum (to cool the blades). The operator is often responsible for sweeping and disposing of debris after milling is complete. An assistant might also be involved, as in a NIOSH (1995) study where a laborer working with a shovel walked beside a large road mill driven by another worker.

As in other construction job categories, the duration of milling activities might vary significantly from shift to shift. For example, at a site evaluated by NIOSH (1995), workers milled a road for more than 8 hours the first day and 3.5 hours as the job was finished the next day. Duration varies even more—from 1 to 8 hours—for smaller milling equipment.

3.10.2 Millers: Exposure Profile

ERG obtained only limited monitoring data on the respirable quartz exposures of workers in this job category. As Table 3-1 indicates, only six full-shift PBZ respirable quartz readings were obtained for millers (NIOSH, 1995; ERG, 2000); of these, four were less than or equal to the LOD (12 $\mu g/m^3$). Two of these readings were obtained for workers operating driveable asphalt milling machines (NIOSH, 1995), and the other two were for workers using a water-fed walk-behind milling machine on terrazzo flooring (ERG, 2000). The highest reading, 340 $\mu g/m^3$, was obtained for a tender working while walking next to a driveable asphalt milling machine during a 504-minute period (NIOSH, 1995). A respirable quartz reading of 230 $\mu g/m^3$ (sample duration 202 minutes) was obtained for the same tender on a second day; this reading is equivalent to an 8-hour TWA of 97 $\mu g/m^3$ (assuming zero exposure for the remainder of the shift) (NIOSH, 1995).

Experimental data and other sources indicate that concrete millers' respirable silica exposure levels can be elevated. For example, PBZ respirable crystalline silica results of 480 to 2,100 $\mu g/m^3$ were associated with multiple 5-minute segments of dry (uncontrolled) milling in a study of wet milling equipment (Echt et al., 2002; NIOSH EPHB 247-15d, 2002). These results, obtained in a covered parking structure using an aluminum cyclone (4.2 liters per minute), indicate the silica concentrations that workers can experience while milling concrete with walk-behind scabblers (also called scarifiers, or surface grinders). Worker typically operate tools of this type for several hours per shift, so their exposure levels can be extremely high.

3.10.3 Millers: Technological Feasibility--Baseline Controls

ERG has divided this job category into four subcategories to describe baseline conditions and control options: (1) workers who operate large driven (or road) milling machines from seats on top of the equipment, (2) milling machine tenders who walk beside the large machines, (3) workers who operate walk-behind milling machines, and (4) workers who operate hand-held milling machines.

Construction workers operating **large driven milling machines** most commonly perform their duties from the tops of the machines. A typical asphalt milling machine has a built-in reservoir from which water is applied to the cutting drum, as mentioned above; however, concrete road milling equipment is not normally equipped with water feeds (NJDHSS, 2001).The machines are available with or without cabs; ERG's sources suggest that cabs are uncommon (NIOSH, 1995; Burstyn et al., 2000). Based on these findings, ERG judged that baseline controls for road milling machines include no cabs or open cabs (which would not provide significant isolation from the outdoor environment) and the use of wet milling methods. The operator's distance from the milling operation also provides some exposure control. As mentioned above, ERG identified two readings, both less than or equal to the LOD of 12 $\mu g/m^3$, for asphalt milling machine drivers associated with these baseline controls (NIOSH, 1995). ERG judges, though, that the exposure level of operators milling concrete roads might be higher. The New Jersey Department of Health and Senior Services (NJDHSS, 2001) reported that, while none of the eight asphalt road millers it evaluated were exposed to respirable silica above the current PEL (average level was 0.5 the PEL), the results for two concrete road millers exceeded the PEL by an average of 1,215 percent. The asphalt milling was performed as a wet process, while the concrete milling was a dry operation (NJDHSS, 2001).

Construction workers **tending large milling machines** most commonly perform their duties while walking beside the machines. Baseline conditions include the use of minimal water sprays for equipment cooling and work performed out of doors. As mentioned above, ERG identified two 8-hour TWA PBZ respirable results for these baseline conditions: 97 $\mu g/m^3$ and 340 $\mu g/m^3$ (NIOSH, 1995).

Millers in the third subcategory operate **walk-behind machines.** Although a vacuum port is typically available on the walk-behind surface preparation equipment currently available, older equipment might not include this feature. Nor do workers necessarily connect an appropriate vacuum to the machine, even when a port is available (Concrete Grinding Company, 2000; Transmatic, undated). Thus ERG considers that baseline conditions for this task do not include engineering controls.

ERG could find no exposure data for U.S. workers operating **hand-held milling tools,** but did identify some foreign worker data. ERG judged that these tools might be used either indoors or outdoors, typically without LEV or wet methods for dust control. Lumens and Spee (2001) collected 53 PBZ respirable crystalline silica samples for concrete recess millers (presumably operating hand-held equipment) in the Netherlands. They obtained results ranging from below the LOD (not provided) to 6,900 $\mu g/m^3$, with a mean level of 700 $\mu g/m^3$ and an average sample period of 6.5 hours. In addition to using conventional milling equipment, some of these workers operated saws and milling equipment fitted with LEV (there was no mention of water-fed equipment milling equipment). In a separate study, Nij et al. (2003) surveyed 13 Dutch recess millers and found that 2 (15 percent) used tools fitted with LEV. Therefore ERG presumes that most of the 53 recess millers evaluated by Lumens and Spee (2001) used no controls. Data obtained in Europe by Hallin (1983) under experimental conditions imply that respirable quartz exposures of hand-held mill operators using no controls continuously throughout an 8-hour shift can be as high as 32,000 $\mu g/m^3$.

3.10.4 Millers: Technological Feasibility—Additional Controls

Additional controls for **operators of driven milling machines** might include enclosed and properly ventilated cabs, as well as consistent use of water and directional spraying specifically for dust control. The effectiveness of this control method is demonstrated by results for eight operators of water-fed asphalt road milling equipment, all of which are below the current PEL (NJDHSS, 2001). These workers' average exposure level is approximately 50 percent of the current PEL.

The same control method (water-fed equipment) is likely to help reduce the exposure level of workers operating concrete road milling equipment. In a study of tunnel construction workers, Blutte et al. (1999) noted that "exposures exceeding the current silica standards were not observed among workers doing concrete removal with large forklifts having grinder or scabbler attachments, most likely due to the use of hoses to wet down the concrete and the greater distance from the source of the silica dust to the worker." However, ERG judges that the available data are not enough to conclude with certainty that workers milling concrete roads would achieve the same exposure level as seen for asphalt millers. The percentage of silica on respirable dust sample filters tends to be higher with concrete milling (15 percent) than with asphalt milling (7 percent) (NJDHSS, 2001). Additionally, the smaller teeth on concrete milling drums produce more fine dust (Schill, 2000). Workers milling concrete roads will need an additional control, such as environmental cabs or respiratory protection.

Hall et al. (2002) showed that, in properly maintained environmental cabs, airborne particulate concentrations can be over 90 percent lower. Bakke et al. (2002) also reported that Norwegian tunnel construction workers who used drills with cabs encountered PBZ respirable quartz levels 90 percent lower than levels for workers using drills without cabs. The average silica result for 22 workers using drills with closed cabs was 31 $\mu g/m^3$, compared to 273 $\mu g/m^3$ for three drill operators working without cabs. These averages are based on samples representing 5 to 8 hours of the workers' 10-hour shifts. In a separate study—mentioned in earlier sections of this report—Rappaport et al. (2003) obtained 46 results for operating engineers on 16 construction sites in the United States; again, they found that using ventilated cabs reduced respirable silica exposure approximately sixfold (80 percent). The median sample duration in this study was 315 minutes.

Additional controls for **tenders of road milling machines** might include a consistent use of directional water spray specifically for dust control, as well as improved work practices and working positioning (e.g., upwind of dust generation). To date, ERG has not been able to determine the availability or effectiveness of these additional measures.

Additional controls for **walk-behind milling machine operators** might include improved water application and LEV. Echt et al. (2002) tested a custom-built water-feed system that provided a copious amount of water (15 gallons per minute) to the work surface. The investigators compared PBZ results from alternating 5-minute periods of milling with and without the water feed activated. The water reduced average respirable dust levels by 80 percent. Due to low filter loading, samples associated with the water control could not be analyzed for crystalline silica, but one measurable respirable dust level of 400 $\mu g/m^3$ was obtained. ERG judged that the crystalline silica level would have been lower, but not necessarily below 100 $\mu g/m^3$ (depending on quartz content of the respirable dust). Work practices contributed to the operator's exposure. Reportedly, the worker generated the most airborne dust when passing the machine over a previously milled area. This second pass disturbed settled particles generated during the first pass, while generating additional particles. Echt et al. noted that a water spray would likely perform as well while using less water.

As mentioned above, ERG found two LOD full-shift respirable quartz readings for walk-behind millers using a water-fed walk-behind milling machine indoors on terrazzo flooring (ERG, 2000). The terrazzo flooring milled during this study contained only trace amounts of crystalline silica, so these readings might be lower than the exposures of operators milling surfaces containing higher levels of crystalline silica.

Wet methods, particularly directional water sprays, offer substantial dust control for other construction workers, including those cutting masonry, grinding concrete, and using impact drills to break concrete. Consistently used directional spray is typically associated with silica results of less than 100 $\mu g/m^3$, and most workers achieve even lower levels. For example seven masonry sawyers using wet methods encountered full-shift PBZ respirable quartz results below 93 $\mu g/m^3$, with a median of 33 $\mu g/m^3$ and a mean of 42 $\mu g/m^3$ (NIOSH ECTB 233-116c, 1999; NIOSH ECTB 233-118c, 1999; OSHA SEP

Inspection Report 113451538; Shields, 2000). This is compared to 8-hour TWA readings up to 2,005 μg/m³, with a median of 52 μg/m³ and a mean of 354 μg/m³, obtained for masonry sawyers cutting dry.[20]

Water spray reduced the exposure levels of a hand-held grinder operator by 90 percent. Although the result of 20 μg/m³ respirable silica might be biased downward, due to sampling difficulties, it suggests that the exposure level during indoor grinding with wet methods was well below 100 μg/m³ and likely below 50 μg/m³ during the 342-minute period of 75 percent active grinding (NIOSH, 1998). Additionally, Zalk (2000) showed that wet methods used by impact drillers can be equally effective indoors and outdoors, producing levels of 100 μg/m³ or less under both conditions.

Some manufacturers of walk-behind milling machines currently offer an LEV option (Trelawny Surface Preparation Technology, 2001; USF Surface Preparation Group, 2001). These options are used generally used for indoor milling operations (Concrete Grinding Company, 2000). A lack of electrical power sources makes the use of LEV outdoors uncommon. A generator is generally needed to power the dust collector, and workers might need to transport the generator with a truck or heavy handcart.

In indoor tests of walk-behind milling machines equipped with dust extractors, Hallin (1983) estimated a median PBZ respirable quartz concentration of 280 μg/m³. In this European study of control equipment, the short-term samples ranged in duration from 10 to 60 minutes. Noting that a significant amount of dust was still released into the surrounding environment, Hallin recommended designing the exhaust train to release dust outside the work space.

According to a representative of Concrete Grinding Company (2000), another concern for most LEV-equipped milling machines is that the dust extractor needs to be shut down and cleared out often, perhaps approximately every 30 minutes. The representative stated that the ease of use and the effectiveness of LEV-equipped milling machines varies by manufacturer, and estimated that the vacuum used by his company collects 80 to 90 percent of the visible dust. Vacuum systems are commercially available for use with shrouded walk-behind surface preparation tools. By some accounts, these systems can reduce total dust by 80 or 90 percent, but their effectiveness in reducing concentrations of the more

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[20]OSHA SEP Inspection Reports 122316805, 122317480, 300444676, 300628344, 300646510, 302547278; Lofgren, 1993; Minnesota OSHA MN-302501929, 2000; NIOSH ECTB 233-118c, 1999.

hazardous respirable silica particles is unproven (Trelawny, 2002; Transmatic, undated). In general, vacuum dust collection decreases airborne dust generated by construction tools, but workers using such methods cannot consistently achieve respirable silica levels below 100 $\mu g/m^3$. This is true for grinder operators and workers using chipping and cutting tools. To date, ERG has not been able to quantify the effectiveness of currently available LEV in controlling respirable quartz levels associated with walk-behind milling operations.

Additional controls for **hand-held milling machine operators** might include wet methods and LEV. ERG has not been able to determine the availability or effectiveness of these additional measures specifically for this type of milling equipment. However, based on the task descriptions, ERG believes that hand-held milling operations are similar to hand-held surface grinding operations.

NIOSH evaluated PBZ respirable silica while a surface grinder and helper smoothed concrete walls in a semi-enclosed construction site. The helper constantly sprayed water just ahead of the grinder blade. Compared to uncontrolled grinding at this site, grinding with the water spray reduced the respirable dust exposure levels by 90 percent. The air sampling pump faulted and was replaced during the evaluation, so the result of 20 $\mu g/m^3$ respirable silica might be biased downward (NIOSH, 1998). Nevertheless, these results suggest that the PBZ exposure level during indoor grinding with wet methods was well below 100 $\mu g/m^3$ and likely below 50 $\mu g/m^3$. Note that during this test the circuit interrupt tripped several times, possibly because water entered a hole in the tool casing and cased an electrical short. Despite this complication, workers performed active grinding for approximately 75 percent of the 342-minute sampling period.

Pre-wetting a surface before grinding appears to be less effective than applying water continuously. Respirable quartz concentrations ranging from 270 to 789 $\mu g/m^3$ were obtained for workers who wetted the walls before beginning tuck-pointing work (OSHA SEP Inspection Report 116192147; Shields, 2000).

Exposure monitoring data from the cut stone industry (SIC 3281) also demonstrates the effectiveness of wet methods for controlling dust during grinding operations. Use of water reduced the average respirable quartz exposure levels of fabricators by 88 percent. Fabricators used water-fed angle grinders to grind granite countertops (Simcox et al., 1999). In this study of four granite shops that switched to water-fed equipment, average respirable quartz concentrations obtained for fabricators at each site were reduced to levels below 70 μg/m^3. ERG concludes that wet methods can be similarly effective in controlling the exposures of surface grinders.

As discussed above, Nij et al. (2003) found that 2 out of the 13 Dutch recess millers they surveyed used tools fitted with LEV. Additionally, 10 of the 13 (77 percent) used tools with water-feed systems. This study also compared short-term (1-minute) PBZ readings for recess millers using no controls and LEV. The respirable dust concentration was reduced by 99 percent when the operator used tools fitted with LEV dust controls.

For **millers of all types** using wet dust control methods in cold weather—like workers in similar categories—might be able to add an environmentally acceptable antifreezing agent to the water supply, assuming that any staining caused by the agent will not cause the product to be rejected. Propylene glycol is an environmentally acceptable antifreeze (ATSDR, 1999). ERG was not able to quantify the effectiveness of this method in reducing exposure.

3.10.5 Millers: Technological Feasibility—Conclusion

Large driven milling machines: ERG concludes that most operators of large asphalt milling equipment already achieve full-shift PBZ respirable quartz exposures less than or equal to 50 μg/m^3. This conclusion is based on the baseline readings described above and the assumption that the water-feed mechanisms on these machines could be adjusted to provide improved dust control, while still cooling the cutting blades. ERG also estimates that operators of large concrete milling machines can achieve silica levels in the range of 50 to 75 μg/m^3 through consistent use of a directional mist water spray, as was shown to be effective for operators of impact drills and masonry saws. Blutte et al. (1999) found that respirable silica results were consistently less than the current PEL (100 μg/m^3) when workers used wet methods while operating large forklifts with concrete grinder or scabbler attachments underground.

Alternatively, as described in the section of this report addressing earth drillers, workers driving large milling machines can achieve respirable silica levels of less than or equal to 50 μg/m^3. Furthermore

ERG judges that, by using the combination of an enclosed cab and wet methods, all operators of large milling machines (asphalt and concrete) can achieve respirable silica levels less than or equal to 25 $\mu g/m^3$. As shown above, and in more detail in the section of this report discussing earth drillers, closed cabs reduce respirable dust concentrations by 90 percent or more and have been effective in reducing the exposures associated with earth drilling.

Tenders of large milling machines: ERG concludes that the full-shift PBZ respirable quartz exposures of most large milling machine tenders might be controlled to a level between 75 and 100 $\mu g/m^3$ when associated with the same water-fed equipment (with properly adjusted spray nozzles) previously discussed for the machines' operators. As noted above in the discussion of additional controls for walk-behind milling equipment, consistent use of directional water mist spray is associated with dramatic exposure reduction for other equipment operators. Although more material is removed by walk-behind milling equipment, the operator is also farther away (approximately 5 to 7 feet) from the cutting blade than are workers using hand-held or hand-operated tools.

Milling equipment tenders might further reduce respirable silica levels by removing milling debris often to prevent resuspension of dust generated as wet material dries. Additionally, workers might move farther from their machines (where practical), allowing dust to dissipate before reaching them. However, ERG has not been able to quantify the effectiveness of these measures in reducing exposures.

ERG concludes that most workers operating small, **walk-behind milling equipment** can achieve respirable quartz levels in the range of 100 $\mu g/m^3$ by using any copious water application method. Furthermore, ERG believes that by using water spray nozzles that provide a directed mist, these workers can achieve levels between 75 and 100 $\mu g/m^3$. ERG has determined that this method can reduce the exposures of workers operating hand-operated concrete chipping and grinding tools to that range; ERG presumes that, for workers operating walk-behind milling equipment, consistent use of wet methods will also be effective. As noted above in the discussion of additional controls for walk-behind milling equipment, consistent use of directional water mist spray is associated with dramatic exposure reduction for masonry sawyers, hand-held grinder operators, and impact drillers. Although more material is removed by walk-behind milling equipment than hand tools, the operator is also farther away (approximately 5 to 7 feet) from the cutting blade than are workers using hand-held or hand-operated tools. The greater distance allows any dust that becomes airborne to dissipate somewhat.

Water attachments are standard for some walk-behind grinding equipment, optional for others (Allen Engineering, 2003; EDCO, 2003).

When wet methods are not possible, LEV can reduce respirable quartz exposures. Nij et al. (2003) reported that respirable dust concentration in short-term (1-minute) samples was reduced by 99 percent when recess millers in the Netherlands used tools fitted with LEV dust controls. As indicated earlier in this report, ERG has determined that LEV methods are effective in reducing the full-shift PBZ respirable quartz exposures of construction workers operating surface grinders. These operators achieved respirable silica levels appropriate for use of half-facepiece respirators. ERG believes that milling tool operators can control their respirable quartz exposures similarly by using equipment with a vacuum connections.

Internationally, both LEV and water-fed milling hand tools are available and widely accepted, as the study by Nij et al. (2003) shows. A review of tool manufacturers indicated that many supply equipment in both the U.S. and Europe.

To further reduce the respirable silica levels of walk-behind milling equipment operators, workers should clean work surfaces often to remove milling debris and prevent resuspension of dust generated as wet material dries. This is critical if the job requires a second pass of the equipment over surfaces already milled (Echt et al., 2002). The available information, however, has not allowed ERG to quantify the effectiveness of this measure in reducing exposure levels.

ERG concludes that workers operating **hand-held milling tools** can achieve respirable crystalline silica levels less than or equal to 100 $\mu g/m^3$ by using wet methods, such as water-fed milling equipment. ERG bases this conclusion on information on workers operating surface grinding equipment in the construction industry and results from workplaces where water-fed milling equipment is used in the cut stone and stone products industry (SIC 3281) (Simcox et al., 1999).

When wet methods are not possible, LEV might be used with hand-held milling machines to control respirable quartz exposures. Nij et al. (2003) reported that in short-term tests, respirable dust concentration was reduced by 99 percent when the operator used tools fitted with LEV dust controls. However, ERG was not able to obtain information quantifying the effectiveness of such systems in controlling respirable crystalline silica exposure levels for U.S. workers using hand-held milling tools.

3.10.6 Millers: References

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3.11 OPERATORS AND TENDERS OF ROCK-CRUSHING MACHINES

3.11.1 Rock Crushers: Process Description

Rock-crushing machine operators oversee the process of crushing rocks, concrete, or construction rubble broken loose by drilling, blasting, and demolition operations. The relatively large pieces (up to about 5 feet across) are crushed down to sizes suitable for various construction uses (to a minimum size of about 1 inch across). It should be noted that rock-crushing operations at fixed sites are considered quarrying operations and fall under the jurisdiction of the Mine Safety and Health Administration. Only "portable" rock-crushing operations, such as those associated with construction sites, fall under OSHA jurisdiction.

The largest pieces of material are delivered to the machine's hopper via a tractor equipped with a bucket attachment. Although some rock-crushing machine operators work from an enclosed control house with tempered air, operators at most construction-site crushing plants work in a "crow's nest" next to the primary hopper, elevated at or near feed height to allow the operator to view the inside of the hopper. The operator manages the machine's controls, oversees the operation, and signals the tractor operator regarding the load dumping operation. The operator's platform is normally about 10 square feet in area and has a fall-prevention railing around it, but it is generally not enclosed (OSHA SEP Inspection Reports 2116507, 11288680). The operator's breathing zone is about 5 to 10 feet from the edge of the hopper opening. The rocks exit the hopper and are carried along conveyor belts into a pile or into secondary and tertiary crushers (Polhemus, 2000; OSHA SEP Inspection Report 2116507).

Some rock-crushing operations employ additional workers, sometimes called belt pickers or utility operators, to tend the machinery. These workers might stand on platforms or on the ground at various points along the moving conveyor belts, ensuring that foreign material (wood, rebar, wire) does not proceed through the process. They might also walk around the grounds to pick up debris that has fallen off the conveyor belts, or clear material that becomes impacted in the crusher, hoppers, or belts. To maintain the line of sight, these workers might lean over a belt or stand several feet away. At one site visited by OSHA, the worker's breathing zone was about 1 foot away from the belt when the worker reached toward it to shift rocks and remove foreign debris (OSHA SEP Inspection Report 300441862).

At sites where no separate employee is to tend the machinery, the operator performs both duties (Haney, 2001; OSHA SEP Inspection Report 300441862).

3.11.2 Rock Crushers: Exposure Profile

Only limited exposure data are available for rock-crushing machine operators (and no data are available specifically for tenders) in the construction industry. As Table 3-1 shows, the five 8-hour TWA PBZ respirable quartz exposure readings, reported in three OSHA inspection reports, range from 172 $\mu g/m^3$ to 1,860 $\mu g/m^3$, with a median of 300 $\mu g/m^3$ and a mean of 798 $\mu g/m^3$. In four out of the five readings, wet methods were in effect during the exposure monitoring (OSHA SEP Inspection Reports 113451975, 300441862). At the site where no water or other engineering controls were used, a reading of 280 $\mu g/m^3$ was obtained for a worker operating a concrete crusher outdoors (OSHA SEP Inspection Report 2116507).

This is the only construction job category in which all 8-hour TWA exposure readings are above 100 $\mu g/m^3$. But at one of the sites, where full-shift respirable quartz PBZ readings of 172 $\mu g/m^3$ and 300 $\mu g/m^3$ were measured, workers stated that conditions were atypical on the day of sampling: the supply of asphalt, which was usually added to the primary hopper to control dust, had run out early in the day. A water hose was aimed at the conveyer instead (OSHA SEP Inspection Report 300441862). Although these data might not represent typical conditions at this site, they indicate the potential for exposure in poorly controlled conditions.

3.11.3 Rock Crushers: Technological Feasibility—Baseline Controls

Based on a review of OSHA SEP inspection reports, ERG concludes that baseline conditions for construction workers who operate and tend rock-crushing machines include the use of some form of dust suppression additive (water or asphalt), but application is either inconsistent or inefficient. Workers typically use no engineering controls or dust-suppressing work practice controls. Of the five sample results obtained for workers in this job category, ERG identified four for rock-crushing machine operators working at baseline conditions, associated with a median of 840 $\mu g/m^3$, a mean of 928 $\mu g/m^3$, and a range of 172 $\mu g/m^3$ to 1,860 $\mu g/m^3$ (OSHA SEP Inspection Reports 300441862, 113451975).

3.11.4 Rock Crushers: Technological Feasibility—Additional Controls

The primary additional controls for this category are using improved water application methods, applying wetting agents and/or dust suppressant materials, installing LEV at the hopper and other locations along the conveyors, and using enclosed operator control stations equipped with LEV. For belt tenders and other workers who must perform tasks near crushing operations, control options include the application of water, wetting agents, and/or dust suppressants; the use of LEV; and work practices that position the worker away from dust-generating processes as much as possible.

As the "Baseline Controls" section indicates, the use of water to suppress dust is associated with a median respirable quartz exposure level of 840 $\mu g/m^3$. ERG judges that the use of greater quantities of water, multiple water spray (mist) outlets into the hopper and along conveyor belts, and better-directed water sprays will effectively reduce the exposures of both machine operators and belt tenders/assistants. Because rock crushing continuously produces new, dry surfaces, ERG judges that large amounts of water are necessary to reduce dust levels—but ERG cannot quantify the amount of water necessary for effective exposure control, in part because information is lacking on the volumes of water currently in use.

Evidence that improved water dust control can reduce silica levels is provided by a full-shift respirable silica level of 54 $\mu g/m^3$ obtained for a crusher operator at a concrete recycling facility using fine-mist water spray (ERG, 2001). This evaluation took place on a day when the incoming concrete was damp with mud and melting ice, which probably contributed to the overall dust suppression; however, the crusher water spray system was designed to maximize the efficiency of this dust suppression method. Multiple water spray nozzles were located at the crusher hopper, the post-crusher conveyer, the sizing screens, and each major transfer point, including the point where crushed material fell to a pile on the ground. The crusher operator controlled the nozzles from a panel in the control booth. The number of nozzles in action varied according to site conditions. The objective was to eliminate all visible dust using the least amount of water. The crusher staff noted that water sprayers were checked frequently and replaced if they became clogged, dripped, or squirted water, rather than producing a mist spray.

At this site, the operator spent much of the shift inside a poorly sealed booth directly over the crusher, but left the booth frequently to spray extra water as it was dumped into the crusher. During the shift, this worker also inspected conveyers and shoveled impacted materials from clogged hoppers and conveyers.

The Mine Safety and Health Administration (1997) recommends applying water ahead of transfer points to allow the water to soak into the material before it falls to the next location. Other sources indicate that for small-scale, high-energy crushing action (pavement breaking with jackhammers), a water mist directed at the crushing zone offers optimal dust control using the minimum amount of water (Zalk, 2000). With this method, the mist engulfing the crushing zone wets fine particles before they can dissipate. ERG cannot quantify the effectiveness of improved water delivery systems in reducing the exposure of rock crushers. However, both Zalk (2000) and NIOSH (2003—EPHB 282-11a) independently showed that a directional mist, adjusted for maximum dust control, reduced jackhammer operator exposure levels by 70 to 90 percent. ERG believes crusher operators could achieve similar reductions.

For the small-scale crushing action of the jackhammer, optimal dust control was achieved using a mist application rate of approximately 1/8 to 1/4 gallon of water per minute (Zalk, 2002; NIOSH EPHB 282-11a, 2003). ERG anticipates that a substantially higher application rate will be required to cover the larger crushing area associated with rock-crushing equipment. The ultimate water usage rate, however, will be considerably lower than if water is applied directly from a hose, allowing a limited supply of water (e.g., from a water truck) to last longer.

In addition to water spraying, the use of other dust-suppressing materials is becoming increasingly popular. One facility reported that workers normally add asphalt into crushing machine intake hoppers to help control airborne dust levels. However, the site was out of asphalt on the day OSHA visited. ERG could not quantify the effectiveness of this method in reducing exposure, and judged that the use of asphalt is limited because of the potential for contaminating the product.

Roe (undated) notes that "The use of foam in crushers is gaining acceptance as a way of reducing dust with minimal added moisture, while maintaining optimum crusher and screening performance." Water expanded into foam provides contact with more dust particles than water in liquid form. One gallon of liquid is converted to between 40 and 100 gallons of foam, available to capture fine particles as fragments of busting bubbles "contact, wet, and agglomerate fine dust particles" (Roe, undated; Polo Citrus, 2003). NIOSH visited a facility in the structural clay (brick) manufacturing industry (SIC 3253) that used a citrus-based foam dust suppressant in crushing equipment. At this site, the foam was added at a conveyer just ahead of the hopper for the pre-crusher, which was used to reduce raw materials (NIOSH ECTB 233-124c, 2000). Numerous manufacturers produce foam dust suppressant agents for use with rock-crushing equipment (Polo Citrus, 2003; The Act Group, 2003; Quarrynews, undated).

Other dust suppression options include steam, which also expands the surface area of liquid water but will not contaminate the product and is easily controlled; and compressed water fog, especially useful when water supply is a problem (Ellis Drewitt & Associates, 1997). A wetting agent (a surfactant added to water to reduce surface tension) might also reduce airborne dust levels at transfer and discharge points.

ERG judged that each of these dust suppressant methods has advantages and disadvantages. Although none can be applied universally to control dust in rock-crushing operations, some of them might offer a substantial benefit if used correctly. Although ERG was not able to quantify the effectiveness of dust suppressants for reducing rock-crusher exposure levels, ERG estimates that when used properly and consistently, they could reduce respirable crystalline silica concentrations at least as effectively as directional water mist spray alone (a 70 to 90 percent reduction).

For rock-crushing operators working during cold weather—as for workers in similar categories— it might be possible to add an environmentally acceptable antifreezing agent to the water supply, assuming the agent is compatible with the ultimate use of the crushed material. Propylene glycol is an environmentally acceptable antifreeze (ATSDR, 1999). ERG was not able to quantify the effectiveness of this method in reducing exposure.

The use of LEV systems at feed hoppers and along conveyor belts might be somewhat effective in reducing respirable quartz levels. The limited data available, however, suggest that LEV alone is not effective in significantly reducing exposure levels associated with mobile crushing equipment. One sample, obtained for an Australian worker crushing quartzite with a dust extraction system as the only control method, resulted in an 8-hour TWA respirable quartz concentration of 300 $\mu g/m^3$ (Ellis Drewitt & Associates, 1997). This result is the same as the median reported in the exposure profile section of this report for rock-crushing machine operators and tenders.

The installation of an isolated and ventilated operator control booth can significantly reduce the respirable quartz exposures of rock-crushing machine operators. In the same study of the South Australian extractive industry, six full-shift respirable quartz results obtained for rock-crushing operators who controlled the dry process from inside air-conditioned cabins ranged from less than or equal to the LOD of 30 $\mu g/m^3$ to 165 $\mu g/m^3$, with a median of 60 $\mu g/m^3$ (Ellis Drewitt & Associates, 1997). At least two of the sampled workers occasionally exited the cabins to free machinery blockages. When compared with the measurement of 300 $\mu g/m^3$ reported above for the rock-crushing operator using LEV but no cabin, the median of 60 $\mu g/m^3$ represents an exposure reduction of 80 percent.

The Mine Safety and Health Administration (1997) recommends several features that enclosed control booths should possess:

- Horizontal and vertical areas should be kept clean and free of debris.
- Door seals and closing mechanisms should work properly. Seals around windows and power line entries, and joints in the walls, floors, etc., should be tightly sealed.
- Air conditioners should be designed so that air comes in from the outdoors to create positive pressure and passes through a prefilter (those with an American Society of Heating, Refrigeration and Air-conditioning Engineers efficiency of 90 percent are common), then a HEPA filter.
- HEPA filters must be changed when they reach the manufacturer's final resistance value.

Operators' cabs reduce exposure in other construction and mining activities, as discussed in previous sections. Rappaport et al. (2003) obtained 46 results for operating engineers on 16 U.S. construction sites, finding that use of ventilated cabs reduced respirable silica exposure approximately sixfold (80 percent). The median result for all operating engineers (with and without cabs) was 75 $\mu g/m^3$, suggesting that engineers in ventilated cabs achieved a substantially lower level. In this study, more than half of the results represented sampling periods greater than 5 hours (the median sample duration was 315 minutes). This is consistent with findings by Hall et al. (2002), who performed simultaneous testing inside and outside cabs. These authors concluded that, in properly maintained environmental cabs, airborne particulate concentrations can be more than 90 percent lower. Bakke et al. (2002) also reported that Norwegian tunnel construction workers who used drills with cabs encountered notably lower PBZ respirable quartz levels than those using drills without cabs. The average silica result for 22 workers using drills with closed cabs was 31 $\mu g/m^3$, compared to 273 $\mu g/m^3$ for three drill operators working without the benefit of cabs. These averages are based on samples representing 5 to 8 hours of the workers' 10-hour shifts.

3.11.5 Rock Crushers: Technological Feasibility—Conclusion

ERG concludes that by using enclosed, properly ventilated operator's booths, most rock-crusher operators can achieve 8-hour TWA respirable crystalline silica exposure levels of 75 $\mu g/m^3$ or less. This is the median exposure level obtained for rock-crushing operators using operator booths in the South Australian extractive industry (described above). This conclusion is based in part on the assumption that the activities of rock-crushing operators in the U.S. are similar to those performed by the Australian fixed plant operators. ERG believes that rock-crushing operators in the U.S. construction industry can achieve similar exposure levels.

Alternatively, reductions of 70 to 90 percent—as reported for concrete breakers using jackhammers—might be achieved through the use of improved water applications and/or other dust suppressant materials at the crusher and along the belts and transfer points. ERG estimates that 20 percent of belt tenders and operators who work outside control booths can achieve exposure levels less than or equal to 75 $\mu g/m^3$ using these methods. Twenty percent represents the proportion of rock crusher operators who are currently exposed to levels of 250 $\mu g/m^3$ or less. A 70 percent reduction in silica levels would produce levels less than or equal to 75 $\mu g/m^3$ for these workers.

A combination of controls will be required for the remaining workers who perform tasks outside enclosed booths. For example, a combination of dust suppression methods (assuming an average 80 percent reduction) and use of an enclosed booth (60 $\mu g/m^3$) for most of the shift could reduce the exposure level of an operator from 1,380 (one of the highest results associated with rock crushing) to less than 100 $\mu g/m^3$. This estimate is for an operator spending no more than 90 minutes total time outside the booth (in brief excursions to clear foreign matter from belts). This example might overestimate the worker's cumulative exposure, as the silica concentration in the booth would likely decrease when dust suppression methods are used. A result of 54 $\mu g/m^3$ was associated with crusher operator using a combination of a booth and wet methods on a muddy day (ERG, 2001)

An alternative combination of controls includes dust suppression methods and respiratory protection. By consistently using properly directed water mist spray at the points indicated above, even the most highly exposed operators and belt pickers can achieve respirable silica levels in a range that is compatible with use of a half-facepiece respirator.

3.11.6 Rock Crushers: References

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3.12 UNDERGROUND CONSTRUCTION WORKERS (TUNNEL WORKERS)

3.12.1 Underground Construction Workers: Process Description

Tunnel construction accounts for most of the construction work performed underground. Tunnel workers who might be exposed to respirable crystalline silica include those in many of the same general construction job categories listed in this report: impact drillers, earth drillers, hand-held drill operators, heavy equipment operators, saw operators, grinder operators, and millers. These workers perform construction and demolition activities on rock, concrete, pavement, and other materials present during various phases of tunnel construction. An additional group of construction workers, tunnel borers, might also be exposed to respirable silica during work with specialized excavation equipment in underground construction. There is no above-ground equivalent for this group.

Several sources report respirable dust and silica exposure information for tunnel construction workers in the United States (Blute et al., 1999; Woskie et al. 2002) and in Europe (Bakke et al., 2002). Although the presentation of job categories does not allow direct comparison in all cases, ERG reviewed these sources and has determined that, in general, PBZ respirable silica concentrations in tunnel construction sites occur over a similar range to that experienced by construction workers performing equivalent tasks in partially enclosed or indoor sites. In fact the range and median exposure levels are lower in some cases, possibly due to OSHA's underground construction standard.

The OSHA standard requires that "the linear velocity of air flow in the tunnel bore, in shafts, and in all other underground work areas shall be at least 30 feet (9.15 m) per minute where blasting or rock drilling is conducted, or where other conditions likely to produce dust, fumes, mists, vapors, or gases in harmful or explosive quantities are present" (29 CFR 1926.800). ERG believes that general ventilation at tunnel construction sites can be superior to that found at many indoor work sites. As a result, respirable silica concentrations are less likely to become elevated in tunnels observing OSHA ventilation requirements than in indoor spaces, for which no such specific ventilation requirement exists. For example, Blute et al. (1999) report respirable quartz levels between 10 and 1,640 $\mu g/m^3$ (mean 280 $\mu g/m^3$) associated with 10 workers using chipping equipment on concrete during the cut and cover phase of tunnel construction. This report's section on impact drillers indicates that the 100 available results for all such workers, operating indoors and out, range from 12 to 3,059 $\mu g/m^3$ (mean 324 $\mu g/m^3$). (See Table 3-1.) Workers in one category—drill operators, in particular roof bolters—are shown to receive higher exposures in tunnels than at other construction sites, perhaps due to increased drilling frequency and a greater proportion of work conducted above chest height.

Most dust control techniques available to the general construction industry (wet methods, LEV-equipped tools, enclosed operator cabs, increased general ventilation) are also available below ground (Blute et al., 1999; Bakke et al., 2002; Tunnel Construction Consultant A, 2003; 29 CFR 1926.800).

Please refer to the appropriate sections of this report for a further discussion of processes, exposure levels, conditions, and silica dust control options available for individual construction job categories (impact drillers, earth drillers, hand-held drill operators, heavy equipment operators, saw operators, grinder operators, and millers).

As mentioned previously, activities associated with tunnel boring equipment have no above-ground equivalent. The remainder of this section describes activities, respirable silica levels, typical working conditions, and exposure control options for workers associated with tunnel boring equipment.

Tunnel borers: For tunneling, construction workers use rapid excavation machines, such as roadheaders and tunnel-boring machines (TBMs). Excavation of the ground within a tunnel might be cyclic (alternating between drilling, blasting, ventilating, and excavating) or semi-continuous (using mining machinery). Note that tunneling for the purpose of extraction, e.g., for coal or minerals, is considered a mining operation and falls under the jurisdiction of the Mine Safety and Health Administration. Tunneling for other purposes is regulated by OSHA.

Several workers are typically needed to operate excavation machines, such as TBMs. A TBM is a cylindrical machine equipped with a cone-shaped cutting head—16 to 18 feet wide on average—that bores through rock. Cutter-head mechanics and drill operators ride inside the machine's enclosed cab during boring operations. Locomotive drivers and brake operators work outside the TBM, operating the engine that carries workers and equipment between tunnel entrances and the TBM. Also working outside the TBM are conveyor belt mechanics, miners who lay track and extend water and air lines as the TBM advances, and electricians who install and extend electrical lines. In the beginning of a project, the TBM may run for only 2 or 3 hours per day. Once the project is established, tunneling operations can proceed for up to 6 hours per shift (NIOSH ECTB 233-119c, 1999; OSHA SEP Inspection Report 1027696576).

NIOSH (ECTB 233-119c, 1999) observed that tunnel workers who perform activities at the bottoms of shafts appear to have the greatest potential for elevated exposure. These workers handle the crew baskets and load and unload material from the locomotives. Their potential for exposure results from their proximity to the conveyor belts while they remove excavated tunnel material and from their exposure to dust carried out in tunnel exhaust air.

3.12.2 Underground Construction Workers: Exposure Profile

Tunnel borers: As Table 3-1 indicates, the 30 8-hour PBZ respirable quartz readings obtained for underground construction (tunnel) workers associated with excavating machines range from less than or equal to 7 $\mu g/m^3$ (the LOD) to 257 $\mu g/m^3$, with a median of less than or equal to 12 $\mu g/m^3$ (the LOD), and a mean of 39 $\mu g/m^3$. These exposure data were obtained at two tunnel construction sites, one evaluated by NIOSH (ECTB 233-119c, 1999) and one by OSHA (OSHA SEP Inspection Report 1027696576). At both sites, TBMs equipped with engineering controls were used. The controls included water sprayers, LEV systems, and shields designed to reduce the release of rock fragments and dust as the TBM cut. ERG could not obtain monitoring data that represent the exposures of workers who perform underground construction using other types of rapid excavation equipment.

The four readings obtained for workers **inside TBMs** ranged from 42 $\mu g/m^3$ to 136 $\mu g/m^3$, with a median value of 67 $\mu g/m^3$. The highest reading was obtained for a mechanic repairing equipment in the TBM for part of the shift, which implies an upset condition (OSHA SEP Inspection Report 1027696576). The report did not specify what equipment malfunctioned.

In 17 of 30 results obtained for workers **outside TBMs,** respirable quartz concentrations less than or equal to the LOD were reported (NIOSH ECTB 233-119c, 1999). One of these LOD readings was obtained for a brake operator who helped load and unload the locomotive flat cars during a 775-minute sampling period (NIOSH ECTB 233-119c, 1999). The highest two readings, 257 $\mu g/m^3$ and 124 $\mu g/m^3$, were obtained at the same site for a worker who loaded and unloaded the locomotive flat cars and assisted with crane operations at the bottom of the tunnel's shaft (NIOSH ECTB 233-119c, 1999).

These levels might under-represent exposure for electricians and operators associated with TBMs. Bakke et al. (2002) reported a median PBZ respirable quartz level of 490 $\mu g/m^3$ for 43 Norwegian TBM workers—substantially higher than levels found by NIOSH in the United States. Due to repairs required on the TBM and ventilation ducts, the Norwegian TBM operated for no more than 25 percent of the 5- to 8-hour sampling periods. Because workers' exposure to respirable silica was reportedly lower when the TBM was not operated, actual airborne concentrations on other shifts might have been even higher. The respirable dust samples in the Norwegian study contained approximately 50 percent more quartz than NIOSH found in their samples (7 to 15 percent), but this alone does not account for the difference in exposure levels. Bakke does not indicate what controls were associated with the TBM or whether the ventilation problems might have been a factor in these elevated silica results.

3.12.3 Underground Construction Workers: Technological Feasibility—Baseline Controls

Tunnel borers: To evaluate baseline and additional controls needed, ERG has divided this job category into two subcategories: workers inside the TBM and workers outside the TBM. To date, ERG has obtained exposure monitoring data only for TBM operations, although other excavating equipment exists.

The primary exposure controls commonly provided (i.e., baseline conditions) for workers **inside TBMs** include water sprays positioned at cutting heads and conveyor transfer points, LEV at cutting heads, and the isolation afforded by enclosed and air-conditioned (but not necessarily air-filtered) cabs. On equipment evaluated by NIOSH, an LEV system at the cutting head scrubbed air with a water filter muffler and featured a bellows and a filter system. The filter system was cleaned according to a prescribed schedule. A review of literature suggests these controls are common to large TBMs. These baseline controls are associated with one reading, 46 $\mu g/m^3$, obtained by NIOSH for a TBM operator who spent a full shift (560 minutes) operating a TBM from within the cab.

The same baseline controls (water spray and LEV on the TBM) reduce respirable silica levels for workers **outside TBMs.** In the tunneling operation evaluated by NIOSH, additional exposure control was provided by the tunnel's forced-air ventilation system. Outdoor air from the top of the shaft was pushed through a 42-inch cloth duct installed along the shaft and the tunnel to the TBM cutting face. At this site, outlet air exited the tunnel shaft at a rate of 35,000 CFM, although the available details are inadequate to compare these measurements with OSHA's existing standard for minimum air velocity (30 FPM through the tunnel cross-section). Two water spray bars positioned at the tunnel conveyor belt transfer points also provided dust control.

ERG identified 18 full-shift respirable quartz readings obtained by NIOSH for workers performing activities where these controls were operating. These 18 results range from less than or equal to 12 $\mu g/m^3$ (the LOD) to 257 $\mu g/m^3$. The median of these results is less than or equal to 12 $\mu g/m^3$; the mean is 33 $\mu g/m^3$. Job titles of sampled workers include welder, electrician, inspector, miner, and conveyor mechanic. The two highest readings in this data, 257 $\mu g/m^3$ and 124 $\mu g/m^3$, were obtained for a worker who loaded and unloaded locomotive flat cars and assisted with crane operations at the bottom of a tunnel's shaft. These readings support NIOSH's observation that the greatest potential for exposure is for workers at the bottoms of tunnel shafts. These exposures are associated with close proximity to the conveyor transfer point and the tunnel shaft, which acts as the exhaust air duct for the tunnel (NIOSH ECTB 233-119c, 1999).

No exposure monitoring data are available on the exposures of underground construction workers using other tunnel-boring equipment, which may lack the type of engineering controls with which TBMs are equipped.

3.12.4 Underground Construction Workers: Technological Feasibility—Additional Controls

The primary exposure controls for workers performing operations **inside TBMs** are water sprays, LEV, and the isolation afforded by the enclosed, ventilated cab. This equipment is associated with a baseline 8-hour TWA respirable silica reading of 46 $\mu g/m^3$ (NIOSH ECTB 233-119c, 1999). The potential for higher exposure when equipment is not functioning optimally is indicated by full-shift results of 136 $\mu g/m^3$ for a mechanic and 87 $\mu g/m^3$ for a TBM drill operator. The mechanic spent part of the shift repairing and servicing the machinery inside the TBM (OSHA SEP Inspection Report 1027696576). The report did not specify which systems were being repaired, but the fact that repairs were being made implies that the equipment was not working at peak efficiency. Furthermore, the OSHA report noted that the tunnel's exhaust system had not been extended the full length of the tunnel, so it provided much less fresh air into the TBM than the equipment's design specifies. The report recommended an increase in the amount of water sprayed on the machine's rotating cutting wheels, and also an increase in the air flow through the TBM's local exhaust system (NIOSH ECTB 233-119c, 1999).

The water sprays and LEV provided by the TBM, as well as the forced-air LEV system running the length of the tunnel, are the primary exposure controls for workers **outside TBMs.** These controls are associated with a baseline median of less than or equal to 12 $\mu g/m^3$. At this site where that measurement was taken, however, the workers at the bottom of the shaft were exposed to full-shift PBZ respirable quartz levels of 257 $\mu g/m^3$ and 124 $\mu g/m^3$ (NIOSH ECTB 233-119c, 1999). NIOSH attributed these elevated levels to the workers' position near the tunnel shaft, which acted as the exhaust air duct for the tunnel's forced-air LEV system. For these workers, however, a possibly more significant factor was their proximity to the transfer point for rock moving from the horizontal belt conveyor to the vertical bucket conveyor. Although a water spray bar was reportedly located at each of two other transfer points in the tunnel, engineering controls were apparently absent from this last transfer point (Echt, 2000). NIOSH recommended the use of a spray bar or LEV at the transfer point or enclosure of the transfer point.

Additional controls for workers outside TBMs, in addition to ensuring the optimal operation of their engineering controls, include enclosing transfer points, improving application of water sprays, and ensuring optimum operation of exhaust systems installed inside tunnels. Studies related to other construction or mining activities indicate that improved water spray quality (droplet size, direction of spray) and quantity (water volume) can increase the effectiveness of water as an exposure control (Zalk, 2000; Flanagan et al., 2001; Thorpe, et al., 1999; Goodman, 2000). The United States Bureau of Mines (1996) suggests maintaining a water pressure of about 100 pounds per square inch in spray systems used for dust control. Filtration helps reduce problems with clogging of spray nozzles from particulates in the water line. But routine nozzle inspection, maintenance, and replacement is still required (ERG, 2001).

Wetting agents might also reduce airborne dust levels at transfer and discharge points. As noted in the rock-crushing job category, however, the contact time necessary for wetting agents to be effective in suppressing dust requires that the water sprays containing wetting agents be applied to the material involved seconds before it reaches the transfer or discharge point. ERG lacks data to quantify the effectiveness of this method in reducing exposure.

For underground construction workers working during subfreezing conditions—as for workers in similar categories—it might be possible to add an environmentally acceptable antifreezing agent to the water supply. Propylene glycol is generally an acceptable antifreeze (ATSDR, 1999). ERG could not quantify the effectiveness of this method in reducing exposure.

Another control option involves increasing the effectiveness of tunnel ventilation systems. The first step in improving a tunnel ventilation system involves ensuring that the duct extends to the face of the tunnel and is free of leaks, that fans provide proper air flow, and that filters are changed regularly—all routine maintenance activities. Additionally, air velocity through the tunnel can be increased above the minimum rates required by OSHA, for example from 30 FPM to 100 FPM. According to the U.S. Bureau of Mines (1996), this higher value is a common design velocity for airflow through tunnels, and should be regarded as a minimum if the rock has more 25 percent crystalline silica. Air velocities two to four times that level have been used when specific operations were anticipated to generate increased amounts of air contaminant.

3.12.5 Underground Construction Workers: Technological Feasibility—Conclusion

Tunnel borers: ERG concludes that for most workers **inside TBMs,** 8-hour TWA respirable silica exposure levels are already in the range of 50 $\mu g/m^3$ when workers have enclosed cabs and water spray and ventilation systems that function as intended. Where exposure levels exceed this value, improved maintenance of cabs, ventilation, and spray systems might will be necessary. This conclusion is based on a full-shift result of 46 $\mu g/m^3$ obtained for a TBM operator whose control equipment appeared to be functioning well (NIOSH ECTB 233-119c, 1999).

ERG further concludes that most tunnel workers associated with but working **outside TBMs** can also achieve silica levels of 50 $\mu g/m^3$ or less using the current control methods in place (water sprays and LEV provided by TBMs, as well as forced-air ventilation systems running the lengths of tunnels). The median result for workers operating under these conditions is less than or equal to 12 $\mu g/m^3$ (NIOSH ECTB 233-119c, 1999).

Additional water spray systems, or more consistent use of them, might be needed to reduce the exposure level of workers at bottoms of shafts, who may be exposed to levels above the current PEL. Every conveyer transfer point should be either treated with spray or covered and exhausted (or both). The available information suggests that, with these additional controls, all workers operating outside TBMs can achieve levels of 50 $\mu g/m^3$.

To date, ERG lacks data on which to base a conclusion for operators of other types of tunneling equipment and associated workers.

3.12.6 Underground Construction Workers: References

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SECTION FOUR

COSTS OF COMPLIANCE

This analysis presents the costs to the construction industry of reducing silica exposures for workers. It covers first the costs of applying appropriate engineering controls to construction activities as required by Table 1 of the draft standard. These costs are generated by the application of known dust-reducing technology, such as the application of wet methods or ventilation systems, as detailed in the technological feasibility analysis. Second, ERG presents estimates of compliance costs ensuing from programmatic requirements as specified in the draft standard.

4.1 UNIT CONTROL COSTS

4.1.1 Representative Jobs

Using the R.S. Means Co. Heavy Construction Cost Data, a standard construction cost estimating guide, ERG defined representative jobs for each silica-generating activity described in the feasibility analysis (Means, 2000). These activities and jobs correspond to the silica-related construction activities listed in Table 1 of the draft standard. Each job was specified in terms of the type of work being performed (e.g., concrete demolition), the makeup of the crew necessary to do the work, and the requisite equipment. For example, for the impact drilling activity, ERG defined three representative jobs for various types of demolition work. For each job, ERG derived crew composition and equipment requirement data from the Means guide and then calculated the per-day baseline cost from the labor rates, equipment charges, material costs, and overhead and profit markups presented in the cost estimating guide. Table 4-1 shows the specifications for each representative job and the associated daily labor and equipment costs. (In one case, drywall finishing, a basic job description is presented twice in order to allow analysis of two different control options later in the analysis.) A summary of the labor rates and equipment charges is presented in Table 4-2.

For example, as shown in Table 4-1, Job 1 for the "drywall finishing " category involves a simple crew, i.e., only two drywall installers. Other crews, such as that for impact drilling, involve several

Table 4-1

Baseline Job Components and Costs

Task Category/ TaskJob Description	Labor: Title	Labor: No. of Workers	Labor: Daily Wage	Labor: Wage Per Min.	Equipment: Description	Equipment: No.	Equipment: Daily Rate	Total Daily Costs: Labor	Total Daily Costs: Equip.	Total Daily Costs: Material	Total Daily Costs: Total
Drywall finishing											
1 Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished	Drywall installers Total	2 2	$729.60	$1.52	Tool cost included in labor rate [a]		$0.00	$729.60	$0.00	$0.00	$729.60
2 Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished (Identical to job 1; included so costs of a different control option can be estimated)	Drywall installers Total	2 2	$729.60	$1.52	Tool cost included in labor rate [a]		$0.00	$729.60	$0.00	$0.00	$729.60
Earth drilling											
3 Drilling only, 2" hole for rock bolts, average	Blast foreman Driller Equipment operator (light) Total	1 1 1 3	$311.20 $286.00 $348.40	$0.65 $0.60 $0.73	Crawler-type drill, 4" Air compressor, 600 cfm 50' air hoses, 3" diameter	1 1 2	$432.41 $236.23 $26.40	$945.60	$695.04	$0.00	$1,640.64
4 Pier holes, 1500 cubic yards of media removed	Blast foreman Driller Equipment operator (light) Total	1 1 1 3	$311.20 $286.00 $348.40	$0.65 $0.60 $0.73	Crawler-type drill, 4" Air compressor, 600 cfm 50' air hoses, 3" diameter	1 1 2	$432.41 $236.23 $26.40	$945.60	$695.04	$39.60	$1,680.24
5 Borings, casing borings in earth, no samples, 21/2" diameter	Laborers Truck driver (light) Total	2 1 3	$572.00 $286.00	$1.19 $0.60	Auger 4"-36" diameter Flatbed truck, 3 ton	1 1	$463.82 $179.25	$858.00	$643.06	$0.00	$1,501.06
Grinding and tuck pointing using hand-held tools											
6 Floors, 1/4" thick, patching concrete	Cement finisher Total	2 2	$664.80	$1.39	Tool cost included in labor rate [a]		$0.00	$664.80	$0.00	$0.00	$664.80
7 Crack repair, including chipping, sand blasting, and cleaning; Epoxy injection up to 1/4" wide	Labor foreman (outside) Laborers Total	1 4 5	$311.20 $1,144.00	$0.65 $2.38	Air tools and accessories Air compressor, 250 cfm 50' air hoses, 1.5" diameter	2 1 2	$33.22 $118.47 $9.24	$1,455.20	$160.93	$15.20	$1,631.33

Table 4-1

Baseline Job Components and Costs

Task Category/ TaskJob Description	Labor				Equipment			Total Daily Costs			
	Title	No. of Workers	Daily Wage	Wage Per Min.	Description	No.	Daily Rate	Labor	Equip.	Material	Total
8 Cut and repoint brick, hard mortar, common bond	Bricklayer	1	$366.00	$0.76	Tool cost included in labor rate [a]		$0.00	$366.00	0	$19.25	$385.25
	Total	1									
Heavy construction equipment operating											
9 Backfill, structural, from existing stockpile, no compaction, 50' haul, sand and gravel	Equip. operator (medium)	1	$367.60	$0.77	Dozer, 200 HP	1	$660.28	$510.60	$660.28	$0.00	$1,170.88
	Laborers	0.5	$143.00	$0.30							
	Total	1.5									
Hole drilling using held-held drills											
10 Drilling for anchors, up to 4" in diameter including bit and layout in concrete or brick walls, no anchor. 3/4" diameter	Carpenter	1	$364.80	$0.76	Tool cost included in labor rate [a]		$0	$364.80	$0.00	$6.30	$371.10
	Total	1									
Impact drilling											
11 Drilling bituminous material, with hand-held air equipment, up to 6 inches thick	Labor foreman (outside)	1	$311.20	$0.65	Breakers, pavement, 60lb	2	$33.22	$1,803.60	$160.93	$0.00	$1,964.53
					Air compressor, 250 cfm	1	$118.47				
	Laborers	4	$1,144.00	$2.38	50' air hoses, 1.5" diameter	2	$9.24				
	Equip. operator, light	1	$348.40	$0.73							
	Total	6									
12 Cutout demolition, elevated slab, bar reinforced, under 6 c.f.	Labor foreman (outside)	1	$311.20	$0.65	Breakers, pavement, 60lb	2	$29.70	$1,455.20	$157.41	$0.00	$1,612.61
					Air compressor, 250 cfm	1	$118.47				
	Laborers	4	$1,144.00	$2.38	50' air hoses, 1.5" diameter	2	$9.24				
	Total	5									
13 Remove masonry walls, block, solid (presumed indoor environment)	Labor foreman (outside)	1	$311.20	$0.65	Air tools and accessories	2	$33.22	$2,190.40	$509.14	$0.00	$2,699.54
					Air compressor, 250 cfm	1	$118.47				
	Laborers	4	$1,144.00	$2.38	50' air hoses, 1.5" diameter	2	$9.24				
	Equip. operators	2	$735.20	$1.53	Front-end loader	1	$348.21				
	Total	7									

Table 4-1

Baseline Job Components and Costs

Task Category/ TaskJob Description	Labor: Title	Labor: No. of Workers	Labor: Daily Wage	Labor: Wage Per Min.	Equipment: Description	Equipment: No.	Equipment: Daily Rate	Total Daily Costs: Labor	Total Daily Costs: Equip.	Total Daily Costs: Material	Total Daily Costs: Total
Masonry cutting using portable saws											
14 Demolition, concrete slabs, mesh reinforcing, up to 3" deep (walk-behind saw)	Equipment operator (light)	1	$348.40	$0.73	Stakebody truck, 3 ton	1	$179.25	$634.40	$280.45	$333.20	$1,248.05
					Concrete saw (walk-behind)	1	$90.64				
	Laborer	1	$286.00	$0.60	Water tank, 65 gal	1	$10.56				
	Total	2									
15 Saw cutting, brick or masonry, with hand-held saw, per inch of depth	Building laborer	1	$286.00	$0.60	Saw, portable cut-off, 8 HP	1	$35.53	$286.00	$35.53	$31.25	$352.78
	Total	1									
16 Saw cutting, concrete walls, hydraulic saw, plain, per inch of depth	Equip. operator (light)	1	$348.40	$0.73	Wall saw, hydraulic, 10 hp	1	$90.64	$634.40	$481.24	$75.00	$1,190.64
					Generator, diesel 100 kw	1	$200.79				
	Truck driver (light)	1	$286.00	$0.60	Water tank, 65 gal	1	$10.56				
	Total	2			Flatbed truck, 3 ton	1	$179.25				
Masonry cutting using stationary saws											
17 Sawing brick or block, per inch in depth	Bricklayer	1	$366.00	$0.76	Tool cost included in labor rate [a]		$0.00	$366.00	$0.00	$0.00	$366.00
	Total	1									
Milling using portable or mobile machines											
18 Asphalt cold planing & cleaning, 1" to 3" asphalt, over 25,000 SY	Labor foreman	1	$311.20	$0.65	Pavement profiler	1	$2,434.52	$2,272.00	$2,928.86	$0.00	$5,200.86
	Laborers	3	$858.00	$1.79	Road sweeper	1	$240.90				
	Equip. oper. (med)	3	$1,102.80	$2.30	Front-end loader (1.75 CY)	1	$253.44				
	Total	7									
19 Concrete surface repair	Labor foreman (outside)	1	$311.20	$0.65	Concrete grinder, floor, electric	1	$53.88	$597.20	$53.88	$0.00	$651.08
	Laborers	1	$286.00	$0.60							
	Total	2									
20 Hand-held milling, wall grinding	Laborer	1	$286.00	$0.60	Wall grinder	1	$28.93	$286.00	$28.93	$0.00	$314.93
	Total	1									

Table 4-1

Baseline Job Components and Costs

Task Category/ TaskJob Description	Labor				Equipment			Total Daily Costs			
	Title	No. of Workers	Daily Wage	Wage Per Min.	Description	No.	Daily Rate	Labor	Equip.	Material	Total
Rock crushing machine tending											
21 Rock crushing, excavation projects	Labor foreman	1	$311.20	$0.65	Rock crushing equipment	1	$2,434.52	$2,272.00	$3,140.39	$0.00	$5,412.39
	Laborers	3	$858.00	$1.79	Front-end loader (1.75 CY)	1	$253.44				
	Equip. operator (medium)	3	$1,102.80	$2.30	Truck, dump, 3 axle, 16 ton payload	1	$452.43				
	Total	7									
Underground (tunnel) construction work											
22 Tunnel construction, bored tunnels including mucking, 20' in diameter, rock excavation (average cost; assumes 100 feet/day)	Total daily crew cost, including equipment ($860 per linear foot)	NA	$12,900.00	$26.88	Tunnel boring machine and support system	1	$73,100.00	$12,900.00	$73,100.00	$0.00	$86,000.00

Source: RS Means Co., Inc., 2001 Heavy Construction Cost Data, 15th Annual Edition. (Kingston, MA, 2000).
[a] Costs for smaller hand-held tools are not separately provided, but are included in the labor rate.

Table 4-2

Labor Wages and Equipment Rates

Labor Categories	Hourly Wage	Hourly Wage With Overhead & Profit [a]
Blast foreman	$24.85	$38.90
Building laborer	$22.85	$35.75
Bricklayer	$29.60	$45.75
Carpenter	$29.15	$45.60
Cement finisher	$27.95	$41.55
Driller	$22.85	$35.75
Drilling foreman	$24.85	$38.90
Equipment operator (heavy)	$31.15	$47.15
Equipment operator (medium)	$30.35	$45.95
Equipment operator (light)	$28.75	$43.55
Labor foreman (outside)	$24.85	$38.90
Laborers	$22.85	$35.75
Oiler	$25.75	$39.00
Skilled worker	$29.85	$46.85
Truck driver (light)	$23.40	$35.75

Equipment Categories	Daily Equipment Rate [b]	Daily Rate With Overhead & Profit [a]
Air compressor, 250 cfm	$107.70	$118.47
Air compressor, 600 cfm	$214.75	$236.23
Air tools and accessories	$15.10	$16.61
Auger 4"-36" diameter	$421.65	$463.82
Breakers, pavement, 60lb	$13.50	$14.85
Core drill, large	$87.94	$96.73
Concrete saw	$82.40	$90.64
Concrete grinder, floor, electric	$48.98	$53.88
Crawler-type drill, 4"	$393.10	$432.41
Crawler dozer, 200 HP	$600.25	$660.28
Dust control, quarry drill	$16.00	$17.60
50' air hoses, 1.5" diameter	$4.20	$4.62
50' air hoses, 3" diameter	$12.00	$13.20
Flatbed truck, 3 ton	$162.95	$179.25
Front-end loader (1.75 CY)	$230.40	$253.44
Front-end loader (2.5 CY)	$316.55	$348.21
Generator, diesel 100 kw	$182.54	$200.79
Horizontal borer, 6 hp	$38.40	$42.24
Hose (water), 20', 2" diameter	$4.50	$4.95
Hose (water), 200', 2" diameter	$45.00	$49.50
Pavement profiler	$2,213.20	$2,434.52
Quarry drill, 5" drifter	$610.20	$671.22
Road sweeper	$219.00	$240.90
Rock crushing equipment	$2,213.20	$2,434.52 [c]
Stakebody truck, 3 ton	$162.95	$179.25
Saw, portable cut-off, 8 HP	$32.30	$35.53
Tunnel boring machine and accessories	NE	$73,100.00 [d]
Truck, dump, 3 axle, 16 ton	$411.30	$452.43
Vacuum, HEPA, 16 gal., wet/dry	$26.16	$28.78
Wall grinder, electric	$26.30	$28.93
Wall saw, hydraulic, 10 hp	$82.40	$90.64
Water tank, 65 gal	$9.60	$10.56
Water tank, engine driven discharge, 5000 gal.	$149.00	$163.90

Source: RS Means, Heavy Construction Cost Data, 2001.
NE=Not estimated
[a] Overhead and profit markups for wages as given by RS Means vary between 48.6 percent and 56.9 percent depending on the labor category. Per RS Means, a 10 percent markup is applied to equipment daily rental costs (but not operating costs).
[b] Based on monthly rental costs averaged over 20 days. Includes operation cost.
[c] Based on costs for pavement profiler.
[d] Estimated at 90 percent of total daily crew and equipment cost, as estimated in Means, 2001.

workers, including equipment operators, and an air compressor. The daily labor cost for the drywall installers is calculated at $729.60. The daily crew costs for representative jobs range from $314.93 per day for milling concrete (Job 20), to $5,412.39 for rock crushing during excavation projects (Job 21), to $86,000 for underground construction work crew capable of tunnel work (Job 22).

4.1.2 Baseline Job Safety Practices

ERG's cost estimates address the extent to which current construction practices incorporate silica dust control measures. Thus, ERG has attempted to use an accurate baseline reflecting such safety measures as are currently employed. To the limited extent that silica dust control measures are employed, ERG has reduced the estimates of incremental costs from the silica control measures.

4.2 ENGINEERING CONTROLS

ERG defined silica dust control measures for each representative job. Generally, these controls involve either a dust collection system or a water-spray approach ("wet method") to capture and suppress the release of respirable silica dust. For each job, ERG estimated the annual cost of the appropriate controls and translated this cost to a daily charge. The unit costs for control equipment were based on price information collected from manufacturers and vendors. In some cases, control equipment costs were based on data from the cost estimating guide on equipment rental charges. Table 4-3 shows the control equipment costs and the assumptions embodied in the daily cost estimates. The estimates of the daily incremental control for each representative job are shown in Table 4-4.

Wet-method controls require a water source (e.g., tank) and hoses. The size of the tank varies with the nature of the job and ranges from a small hand-pressurized tank (Job 15) to a large tank for earth drilling operations (Job 4). Depending on the tool, dust collection methods entail vacuum equipment, including a vacuum unit and hoses, and either a dust shroud or an extractor. For example, concrete grinding operations using hand-held tools (Jobs 6 and 7) require dust shroud adapters for each tool and a vacuum. The capacity of the vacuum depends on the type and size of tool being used. Some equipment,

Table 4-3

Unit Control Costs

Equipment Category	Equipment Cost	Average Lifetime (yrs)	Average Annualized Cost	Average Ann. Cost/ Day of Use	Maintenance and Operating Cost/Day [a]	Total Ann. Cost/ Day of Use	Source; Comments
Wet kit, with water tank	$290	2	$160.40	$0.67	$0.23	$0.90	Masonrytools.com, 2001
Dust shrouds: chipping hammers, needle scalers, etc.	$60	1	$60.00	$0.25	$0.09	$0.34	Shave Away
Water tank, portable (unspec. capacity)	NA	NA	NA	$10.56 [b]	$2.64	$13.20	RS Means - based on monthly cost
Water tank, small capacity (hand pressurized)	$63	1	$67.94	$0.28	$0.10	$0.38	Dynabrade, Hudson - median
Hose (water), 20', 2" diameter	NA	NA	NA	$4.95 [b]	$1.24	$6.19	RS Means - based on monthly cost
Custom water spray nozzle and attachments	$200	1	$214.00	$0.89	$0.31	$1.20	NIOSH (February, 2003); Includes attachments for use in high-impact applications.
Hose (water), 200', 2" diameter	NA	NA	NA	$49.50	$12.38	$61.88	RS Means - based on monthly cost
Vacuum, 10-15 gal	$783	2	$432.79	$1.80	$0.63	$2.43	Porter cable, Milwaukee, median
Vacuum, large capacity	$1,898	2	$1,049.49	$4.37	$1.53	$5.90	Sawtec, median
HEPA filter and attachment, small vacuum	$650	2	$359.51	$1.50	$0.52	$2.02	Edco
HEPA filter and attachment, large vacuum	$900	2	$497.78	$2.07	$0.73	$2.80	Edco
Dust collector for hand-held tools	$359	1	$384.13	$1.60	$0.56	$2.16	Makita
Dust extraction kit (rotary hammers)	$30	1	$30.00	$0.13	$0.04	$0.17	Makita
Dust control/quarry drill	NA	NA	NA	$17.60 [b]	$4.40	$22.00	RS Means Heavy Construction Cost Data 2001, pg 21; based on monthly cost
Drywall sanders w/ vacuum connection and hose	$100	1	$100.00	$0.42	$0.15	$0.56	ERG estimate of incremental cost of sander with vacuum attachment
Cab enclosure /w ventilation and air conditioning	$13,000	10	$1,850.91	$7.71	$2.70	$10.41	Estimates from equipment suppliers and retrofitters
Foam dust suppression system	$14,550	10	$2,071.59	$8.63	$162.16	$170.79	Midyett, 2003.
Water tank, engine driven discharge, 5000 gal.	NA	NA	NA	$163.90 [b]	$40.98	$204.88	RS Means - based on monthly cost
Half-face respirator	$27	2	$468.74	$1.95	$0.49	$2.44	See note c.
Tunnel dust suppression system supplement	$7,928	5	$1,933.47	$8.06	$2.01	$10.07	Raring, 2003.

Source: ERG estimates based on vendors' equipment prices and RS Means, Heavy Construction Cost Data, 2001.
NA=Not applicable. For cost items that are assumed to be leased or rented (as on a per job basis), equipment lifetimes are not relevant and have not been defined.
[a] Except where noted, daily equipment costs are inflated by an operating cost factor of 0.1 and a maintenance cost factor of 0.25.
[b] Daily equipment costs derived from RS Means include operating costs.
[c] Derived by ERG based on vendor-derived capital cost of $27.00, 2 year equipment life, accessory cost of $295.52. Also includes annualized training cost of $50.34, fit test cost of $26.45, and respirator cleaning cost of $81.49 to derive total annual costs of $468.74.

Table 4-4

Silica Control Methods, Specified by Activity

Task Category/ Task Description	Control Method	Control Method Cost Summary	Indirect Labor Cost/Day (Due to productivity penalty)				Incremental Equipment Cost/Day			Total Incremental Cost
			Title	Percentage Productivity Penalty	Cost per Worker Affected	Productivity Penalty Cost	Description	Daily Cost [a]	Total	
Drywall finishing										
1 Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished	Dust collection	Setup and operate dust control system	Drywall installers	4.0%	$29.18	$29.18	Vacuum, 10-15 gal HEPA filter and attachment for small vacuum Drywall sanders w/ vacuum connection and hose (one each per worker)	$4.87 $2.02 $1.13	$8.02	$37.20
2 Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished (Identical job w/different control)	Use non-silica finishing compound	Use of substitute (Identical job assumed w/ different control)	NA	0.0%	$0.00	$0.00	Use of substitute finishing compound	NA	$0.00	$0.00
Earth drilling										
3 Drilling only, 2" diameter hole for rock bolts, average	Dust collection	Setup and operate dust control system	Blast foreman Driller Equip. operator, light	0.0%	$0.00 $0.00 $0.00	$0.00	Dust control/quarry drill Water tank, portable (unspec. capacity) Hose (water), 20', 2" diameter Custom water spray nozzle	$22.00 $13.20 $6.19 $1.20	$42.59	$42.59
4 Pier holes, 1500 cubic yards of media removed	Dust collection	Setup and operate dust control system	Blast foreman Driller Equip. operator, light	0.0%	$0.00 $0.00 $0.00	$0.00	Dust control/quarry drill Water tank, portable (unspec. capacity) Hose (water), 20', 2" diameter Custom water spray nozzle	$22.00 $13.20 $6.19 $1.20	$42.59	$42.59
5 Borings, casing borings in earth, no samples, 21/2" diameter	Dust collection	Setup and operate dust control system	Laborers Truck driver (light)	0.0%	$0.00 $0.00	$0.00	Dust control/quarry drill Water tank, portable (unspec. capacity) Hose (water), 20', 2" diameter Custom water spray nozzle	$22.00 $13.20 $6.19 $1.20	$42.59	$42.59
Grinding and tuck pointing using hand-held tools										
6 Floors, 1/4" thick, patching concrete	Dust collection	Setup and operate dust control system	Cement finisher	5.0%	$33.24	$33.24	Vacuum, large capacity HEPA filter and attachment for large vacuum Dust shroud adapter	$5.90 $2.80 $0.34	$9.04	$42.28
7 Crack repair, including chipping, sand blasting, and cleaning. Epoxy injection up to 1/4" wide.	Dust collection	Setup and operate dust control system	Labor foreman (outside) Laborers	5.0%	$15.56 $57.20	$72.76	Vacuum, large capacity HEPA filter and attachment for large vacuum Dust shroud adapter (4; 1 per worker)	$5.90 $2.80 $1.35	$10.05	$82.81
8 Cut and repoint brick, hard mortar, common bond.	Dust collection	Setup and operate dust control system	Bricklayer	5.0%	$18.30	$18.30	Dust Shroud Vacuum, 10-15 gal HEPA filter and attachment for small vacuum	$0.34 $2.43 $2.02	$4.79	$23.09

Table 4-4

Silica Control Methods, Specified by Activity

Task Category/ Task Description	Control Method	Control Method Cost Summary	Indirect Labor Cost/Day (Due to productivity penalty)				Incremental Equipment Cost/Day			Total Incremental Cost
			Title	Percentage Productivity Penalty	Cost per Worker Affected	Productivity Penalty Cost	Description	Daily Cost [a]	Total	
Heavy construction equipment operating										
9 Backfill, structural, from existing stockpile, no compaction, 50' haul, sand and gravel	Cab enclosure	NA	Equip. operator, (medium) Laborers	0.0%	$0.00 $0.00	$0.00	Incremental cost for enclosed cab	$10.41	$10.41	$10.41
Hole drilling using held-held drills										
10 Drilling for anchors, up to 4" in diameter including bit and layout in concrete or brick walls, no anchor. 3/4" diameter	Dust collection	Setup and operate dust control system	Carpenter	2.0%	$7.30	$7.30	Dust extraction kit Vacuum, 10-15 gal HEPA filter and attachment for small vacuum	$0.17 $2.43 $2.02	$4.63	$11.92
Impact drillers										
11 Drilling bituminous material, with hand-held air equipment, up to 6 inches thick	Wet methods	Setup and operate hose/sprayer	Labor foreman (outside) Laborers Equip. operator, light	3.0%	$9.34 $34.32 $10.45	$54.11	Hose (water), 20', 2" diameter Air tools and accessories Custom water spray nozzle	$13.20 $6.19 $1.20	$20.59	$74.70
12 Cutout demolition, elevated slab, bar reinforced, under 6 c.f.	Wet methods	Setup and operate hose/sprayer	Labor foremen Laborer	3.0%	$9.34 $34.32	$43.66	Water tank, portable (unspec. capacity) Hose (water), 20', 2" diameter Custom water spray nozzle	$13.20 $6.19 $1.20	$20.59	$64.25
13 Remove masonry walls, block, solid (indoor environment)	Dust collection	Setup and operate dust control system	Labor foremen Laborer Equip. operators	5.0%	$15.56 $57.20 $36.76	$109.52	Vacuum, large capacity HEPA filter and attachment for large vacuum Dust shroud adapter (2; 1 per equip. oper.)	$5.90 $2.80 $0.68	$9.38	$118.90
Masonry cutting using portable saws										
14 Demolition, concrete slabs, mesh reinforcing, up to 3" deep	Baseline includes controls, but addit. efforts needed	Properly maintain wet-method control	Equip. operator, light Laborer	2.0%	$6.97 $5.72	$12.69	Only incremental maintenance required Captured in productivity penalty	$0.00	$0.00	$12.69
15 Saw cutting, brick or masonry, with hand-held saw, per inch of depth	Wet methods	Setup and operate water attachment accessory	Building laborer	2.0%	$5.72	$5.72	Wet kit with water tank	$0.90	$0.90	$6.62
16 Saw cutting, concrete walls, hydraulic saw, plain, per inch of depth	Baseline includes controls, but addit. efforts needed	Properly maintain wet-method control	Equip. operator, light Truck driver (light)	2.0%	$6.97 $5.72	$12.69	Only incremental maintenance required Captured in productivity penalty	$0.00	$0.00	$12.69

Table 4-4

Silica Control Methods, Specified by Activity

Task Category/ Task Description	Control Method	Control Method Cost Summary	Indirect Labor Cost/Day (Due to productivity penalty)				Incremental Equipment Cost/Day			Total Incremental Cost
			Title	Percentage Productivity Penalty	Cost per Worker Affected	Productivity Penalty Cost	Description	Daily Cost [a]	Total	
Masonry cutting using stationary saws										
17 Sawing brick or block, per inch in depth	Baseline includes controls, but addit. efforts needed	NA	Bricklayer	2.0%	$7.32	$7.32	Only incremental maintenance required. Captured in productivity penalty	$0.00	$0.00	$7.32
Milling using portable or mobile machines										
18 Asphalt cold planing & cleaning, 1" to 3" asphalt, over 25,000 SY	Baseline includes controls, but addit. efforts needed	Properly maintain wet-method control	Labor foreman Laborers Equip. oper. (med)	2.0%	$6.22 $17.16 $22.06	$45.44	Only incremental maintenance required Captured in productivity penalty	$0.00	$0.00	$45.44
19 Concrete surface repair	Wet methods	Setup and operate water attachment accessory	Labor foreman (outside) Laborers	2.0%	$6.22 $5.72	$11.94	Vacuum, large capacity HEPA filter and attachment, large vacuum	$5.90 $2.80	$8.70	$20.65
20 Hand-held milling, wall grinding	Dust collection	Setup and operate dust control system	Laborer	5.0%	$5.72	$5.72	Vacuum, 10-15 gal HEPA filter and attachment, small vacuum	$2.43 $2.02	$4.46	$10.18
Rock crushing machine tending										
21 Rock crushing, excavation projects	Wet method	Setup and operate foam dust suppression system	Labor foreman Laborers Equip. operator	0.0%	$0.00 $0.00 $0.00	$0.00	Foam dust suppression system	$170.79	$170.79	$170.79
Underground (tunnel) construction work										
22 Tunnel construction, bored tunnels including mucking, 20' in diameter , rock excavation (average cost; assumes 100 feet/day)	Supplemental spray points in dust control system	Install 3 addit. spray points in material handling	Tunnel crew	0.0%	$0.00	$0.00	Equipment cost of supplemental water spray points in dust control system	$10.07	$10.07	$10.07

Source: ERG estimates.
[a] See Table 4-3

such as concrete floor grinders, comes equipped with a dust collection system and a port for a vacuum hose. The estimates of control costs for those jobs using dust collection methods assume that an HEPA filter will be required.

4.3 INCREMENTAL LABOR COSTS AND PRODUCTIVITY IMPACTS

In addition to incremental equipment costs, ERG estimated the incremental labor costs generated by implementing silica dust controls. The labor costs are generated by 1) the extra time needed for workers to set up the control equipment, 2) potential reductions in productivity stemming from use of the controls, 3) additional time to service vacuum dust control equipment, and 4) additional housekeeping time associated with or generated by the need to reduce exposures. All use-related labor costs have been subsumed into a single productivity penalty estimate for the representative job categories. To compile data on productivity impacts, ERG interviewed equipment dealers, selected construction contractors, industry safety personnel, and researchers working on construction health topics.

Because most silica dust controls are not widely used, knowledge about the impact of dust controls on productivity was uneven and quite limited. More precisely, few individuals are in any position to compare productivity with and without controls. Very few controlled studies were identified in the literature. Overall, telephone contacts produced a variety of opinions on productivity effects, but very few quantitative estimates. Equipment rental agencies and construction firms estimated the largest productivity impacts claimed. Some equipment vendors suggested there are positive productivity effects from control equipment due to improved worker comfort (from reduction in dust levels). Others suggested that the use of dust collection equipment reduces or eliminates the need to clean up dust after job completion.

The estimation of productivity effects is also complicated by the highly job- and site-specific factors that influence silica dust exposures and requirements for silica dust control. Potential exposures vary widely with hard-to-predict characteristics of some specific work tasks (e.g., characteristics of materials being drilled), environmental factors (e.g., wet or dry conditions, soil conditions, wind conditions), work locations (e.g., varying dust control and dust cleanup requirements for inside or outside jobs), and other factors. Generalizations about productivity impacts, therefore, are hampered by the range of silica dust control requirements and work circumstances.

After considering the existing evidence, ERG judged that productivity impacts are often likely to occur. Depending on the general likelihood of productivity impacts for each activity, ERG selected a productivity impact ranging from zero to a negative 5 percent of output. The factors influencing each selection are described below.

Table 4-5 summarizes the productivity estimates. While quantitative data are quite limited on productivity, it is possible to gauge the relative productivity effects across the principal control options. For example, ERG judged that there is no productivity penalty for certain controls, such as enclosing an operator's cab on heavy construction equipment. (In that case, the productivity impacts might be positive.)

4.4 PRODUCTIVITY IMPACT ESTIMATES, BY TASK

- **Drywall Finishing**: To reduce respirable silica dust exposures during drywall finishing, workers can use non-silica containing drywall compound or use LEV attachments. In the first case, there is no incremental cost or productive impact. This control approach is forecast to be most common.

For the latter case, workers must use sanders (either powered or hand) with a port for a vacuum attachment. This requirement does not impose design limitations on the sanding head, so the changes to tool design do not generate productivity impacts. NIOSH studies of the effectiveness of dust controls during short-duration tests showed no significant productivity impacts associated with dust controls (Mead, et al., 1995). In selected circumstances, the dust control equipment might also reduce the need to seal work areas to prevent dust migration to other areas. Reduced dust may also facilitate subsequent painting because less surface cleaning is needed. Further, NIOSH has speculated that workers in cleaner work environments would tend to be more productive, would take fewer breaks for fresh air, and would be absent less frequently (NIOSH, 1999).

Table 4-5

Productivity Penalty Estimates for Affected Construction Projects

Productivity Penalty	Source/Rationale for Productivity Impacts	Job Categories Affected
None	Dust control is well-integrated into equipment; control set-up can be accomplished with little or no additional effort or as part of substantial set-up effort. (In some cases, dust control can improve worker comfort and might enhance productivity.)	Earth drilling; Rock crushing; Operators of tractors and heavy equipment; Drywall finishing (where non-silica finishing compound is used); Underground (tunnel) construction workers
2% (approx. 10 minutes/day)	(1) Dust control requires incremental set-up time, or (2) Incremental maintenance, or (3) Additional clean-up (Controls have little impact on job performance)	Millers using portable or mobile machines (when wet methods are used); Hole drilling using hand-held drills; Masonry cutting using stationary saws; Masonry cutting using portable saws
3% (approx. 15 minutes/day)	Dust control requires incremental set-up time and some increase in maintenance or clean-up requirements	Impact drilling (wet methods)
4% (approx. 19 minutes/day)	Dust control requires incremental set-up time and regular maintenance during day, but reduces job cleanup	Drywall finishing (when LEV is used)
5% (approx. 24 minutes/day)	Dust control requires incremental set-up time and regular maintenance during day	Impact drilling (where LEV is used) Grinding and tuck-pointing Millers using portable or mobile machines (when LEV is used)

Nevertheless, based on its various contacts to knowledgeable industry personnel and researchers, ERG judges that workers' use of an attached vacuum hose will generally slow workers and hourly output will be reduced. Furthermore, workers must periodically empty vacuum bags or barrels and, possibly, clean and unplug filters. These incremental task requirements might sometimes be partly offset by a reduction in the time required to clean up after the job. Nevertheless, some dust cleanup is still likely to be required. Based on these considerations, ERG judged that there would be a net negative productivity impact equal to 4 percent of the workers time associated with use of drywall sanding dust controls.

- **Earth Drillers**: This activity category covers a range of drilling activities using truck-mounted and similar drilling equipment, such as quarry drills and crawler-type drills. Dust control requires either use of a dust collection system, or wet drilling methods. Studies of the effectiveness of available dust collection systems have not addressed performance issues, but ERG judges that their use does not affect drilling productivity. While workers must service the dust control equipment during the workday, this activity generally does not affect the rate of drilling, except perhaps for short-duration jobs. The wet drilling methods are integrated into drilling equipment and also should not adversely affect the drilling rate. Thus, ERG estimated there was no productivity penalty for this category.

- **Grinding and Tuckpointing:** Grinding tools can be retrofit with dust control shrouds that connect to a vacuum system (Buser, 2001 and Buser, 2002). The available literature on these controls indicate that dust shrouds and vacuums require extra time to install the shroud and periodically clean, empty, or replace the vacuum drums, filters, or bags. The sources estimate that installation time may be as short as five minutes, although some types of shrouds take longer to install. Once installed, however, the shroud can be left in place, so this activity need not take place at the initiation of each grinding job.

For interior jobs and for exterior work that requires site cleanup of grinding debris, the additional work time required to use a vacuum system might be partially offset by savings in the time required to seal work areas (to prevent dust migration) and to clean the work area after task completion. Overall, clean up times will vary depending on the size of the job site, the quantity of grinding debris, and the strength and capacity of the vacuum.

Grinding without a dust-control shroud can generate clouds of dust that might impair a worker's views of the grinding area. Metal shrouds also block worker views of the grinding area, although plastic shrouds allow workers a view of the work area. Some contractors have noted, however, that use of shrouds does not allow for the precision required for certain tasks, such as grinding an inside corner (Lattery, 2001).

For exterior jobs where clean up is not required, the use of vacuum equipment imposes a clear productivity penalty for servicing the vacuum collectors. If, for example, five minutes were required to empty the vacuums every two hours, productivity would decline about 4 percent, due simply to dump the accumulated dust.

At some construction sites, vacuums have been used during the grinding process, but without shrouds. In these cases, one worker typically holds the vacuum nozzle near the grinding tool, which another worker operates. Switching to shrouds with a direct vacuum attachment would eliminate the need for this assistant and is a more productive operation.

Manufacturers and vendors cited other benefits from using the shroud-vacuum systems. Because dust does not build up on and clog the surface of the grinding wheel, they last longer, resulting in an approximate 40 percent savings on the grinding discs (Eurovac, 2001). Another contact estimated that shrouds can increase the abrasive life of a grinding wheel by more than 500 percent (Buser, 2002). In this regard, workers would spend slightly less time replacing wheels over the life of the equipment.

ERG concluded that while the productivity impacts of vacuum systems can sometimes be partly offset by other factors, net productivity impacts are likely to remain negative. For exterior work, productivity is clearly lower when workers use a vacuum system. Overall, ERG used a 5 percent productivity penalty for calculating compliance costs.

For a tuckpointing project, NIOSH researchers examined the use of vacuum system controls at a large college building complex (Gressel et al., 1999). Workers used a shroud-vacuum system with an integral impeller and a fabric dust collection bag. This system required emptying the collection bags about once an hour. The authors reported some problems caused by blocking and kinking of the hose and occasional separations of the hose from the tool. Some of these problems can be attributed to the design of the dust control system and might be rectified by future design innovations. Overall, the vacuum control systems appeared to reduce worker output.

Manufacturers and vendors contacted by ERG estimated that polyurethane shroud-vacuum systems with tuck-pointing equipment, similar to those for hand-held grinders, actually enhance productivity. The commenters gave several reasons for the enhancement, including that fewer workers were required, clean up times were reduced, and workers had improved visibility of the work surface and longer blade life (Buser, 2002; Caperton, 2002; Eurovac, 2001; Williams, 2002). These estimates were made for tuck pointers with 2- to 8-inch diameter wheels. Effects on worker productivity have also been reported for shrouds that fit on 5-inch and 7- to 8-inch (18-lb) tuck pointers with integrated dust-collection systems. In these tools, an impeller inside the tool housing pushes dust down a hose into a reusable dust-collection bag. It has been estimated that the operational productivity of these tools is no different from that of the same tool without dust control capability. Workers would still be required, however, to periodically empty dust bags, although other clean up time might be somewhat reduced. Because tuck-pointing work is almost exclusively exterior work, however, clean up is often not required.

Based on the considerations for hand-held grinding tools discussed above and the findings from the NIOSH tuck-pointing study, ERG judged that use of a vacuum system during tuck-pointing operations would impose on average a 5 percent productivity impact. Manufacturer optimism about the productivity impacts has not been documented in controlled studies.

- **Heavy Construction Equipment Operators**: The proposed control method is to enclose and ventilate the operator's cab. Using an enclosed cab will not require maintenance beyond the general equipment necessary to maintain the integrity of the cab enclosure. No productivity loss will be incurred.

Some equipment operators might experience an increase in productivity due to improved comfort. Most vendors of heavy construction equipment or of retrofit cab enclosures argue that such gains will occur. Similar arguments have also been made when equipment cabs have been enclosed for other reasons, including for noise control (Meitl, undated). The significance of the productivity gain at any particular site will depend upon many factors, including the interaction of heavy equipment operation with other job site activities. Productivity benefits will not result when the heavy equipment work is not on the critical path for advancing the day's outputs, i.e., such as when the equipment operator works in conjunction with other workers and must frequently wait for other workers to complete complementary tasks.

ERG did not identify quantitative studies of the productivity increase from enclosing the cab. To be conservative, ERG did not quantify the potential productivity gain that might accrue on average over construction tasks.

- **Hole Drillers Using Hand-Held Tools**: Activities in this category range from core drilling to drilling anchor holes in concrete. Core drills are designed with a water flushing capability, while other drills and rotary hammers use a shroud and vacuum arrangement to control dust. Core drilling (large diameter holes) in concrete is typically done wet, and the equipment is designed for the recovery of the water coolant.

One rock-drill manufacturer asserts that use of vacuum systems speed the drilling by continuously removing the drill cuttings from the hole, obviating the need for workers to periodically stop drilling to accomplish this task (Atlas-Copco, 2001). On the other hand, the connection and servicing of the vacuum equipment requires incremental work and can reduce productivity. If the specific construction project involves interior work, this impact might be offset by reductions in the time necessary for cleanup. Interior work would require clean up, while exterior drilling probably would not. Overall, ERG assumed a 2 percent productivity penalty in estimating compliance costs.

- **Impact Drillers**: Silica exposures generated during pavement breaking, concrete demolition, and other concrete work using jack hammers, pavement breakers, and other similar tools are controlled through the use of wet methods. Because the work area generally cannot be presoaked effectively (i.e., dust is generated once impact drillers break through the surface), ERG judges that adequate dust control requires a constant spray of water to the work area. Thus, dust control requires that a water sprayer be mounted onto the jackhammer (or that a mobile sprayer be set up that can move along with the work). Alternatively, a crew member can use a water hose to spray and wet the concrete and asphalt surfaces being broken, although the productivity loss in that case is substantial and construction firms are likely to avoid this approach.

ERG judges that the incremental productivity impact from the spraying activity is modest, however, because various crew could be occasionally enlisted to keep the water spray directed in the correct location. Further, because of the interactive nature of the various crew members' activities, the time to move the water sprayer is unlikely to affect the overall crew output. Incremental cleanup costs generally would not be significant either since most drilling projects are performed outside. Nevertheless, to allow for some incremental work related to supplying water and positioning the spray, ERG estimated a 2 percent productivity decline.

• **Masonry Cutters Using Portable (Hand-Held and Walk-Behind) Saws**: Large, walk-behind saws have an integrated water tank, and the sawing is almost always done wet. Wet sawing keeps the blade from overheating, with the water acting as coolant. No incremental costs or productivity impacts are forecast for use of this equipment.

As has been noted, most portable hand-held concrete saws are designed with wet-sawing capability. These saws have a water-hook up for a hose attachment, but might also be used for dry cutting. (Dry-cut diamond blades for dry cutting are available; these are made specially so that the tips do not separate during dry cutting.)

A construction equipment distributor judged that there are no operational productivity advantages for dry cutting, as opposed to wet. Wet cutting, however, requires access to water (water line or pressurized tank), and some time is needed to connect the equipment. Further, the water hose hookup can be cumbersome and interfere with the work. (Healy, 2002). For these reasons, ERG has assigned a 2 percent productivity impact for using wet methods for hand-held concrete saws.

• **Masonry Cutters Using Stationary Saws**: Stationary saws for masonry, brick, and tile cutting come equipped with water systems for wet cutting, which is the conventional, baseline method for this type of work. Some modest incremental time is needed to provide for and connect the water supply and to maintain the water nozzles and spray system. This incremental time was the basis for a 3 percent productivity decline.

• **Millers Using Portable or Mobile Machines:** These activities range from cold planing and cleaning of asphalt to surface planing or grinding of concrete. In large-scale projects, such as a street resurfacing project, baseline practices are judged to control silica dust exposures. No controls or productivity impacts are expected.

While some grinding machines for milling concrete surfaces have built-in dust collection or wet-method systems, others must be attached to external vacuum equipment. Based on the available literature, ERG did not identify any reports that the grinding operation, per se, is slowed when such vacuum equipment is attached. Nevertheless, workers must devote some time to equipment setup and to changing vacuum bags or barrels and cleaning filters. ERG judged that there would be a 2 percent productivity decline for milling using wet methods and a 5 percent productivity penalty when using LEV systems.

• **Rock Crushing Machines and Tenders:** ERG forecasts that rock crushing units will be modified to operate automatic dust suppression systems. Once installed, these systems will be part of the rock crushing machine operation and will not impact production rates. Thus, no productivity impacts were forecast for this job category.

• **Underground (tunnel) construction workers:** Underground tunneling operations currently use the pertinent dust control measures. Any increase in maintenance of systems generates a negligible incremental work requirement and is forecast to have no impact on crew productivity.

4.5 BASELINE AND INCREMENTAL UNIT CONTROL COSTS

Table 4-6 summarizes the baseline costs and incremental compliance costs for each representative job. The incremental compliance costs are the sum of additional labor and equipment costs related to the provision and use of silica controls. Thus, the productivity impacts of silica controls generate incremental labor costs and the silica control equipment generates incremental control costs.

The control costs (defined as incremental costs per day) are shown as a percentage of the baseline daily job costs. These percentages are then used (see Table 4-7) in calculating the weighted average

Table 4-6

Incremental Control Costs as a Percentage of Activity Costs

	Task Category/ Task Description	Total Daily Baseline Cost	Controls	Productivity Penalty	Incremental Labor Cost/Day	Incremental Equipment Cost/Day	Total Incremental Cost/Day	Total Incremental Costs as % of Baseline Costs
Drywall finishing								
1	Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished	$730	Dust collection system	4.0%	$29.18	$8.02	$37.20	5.1%
2	Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished (Identical job w/different control)	$730	Use non-silica finishing compound	0.0%	$0.00	$0.00	$0.00	0.0%
Earth drilling								
3	Drilling only, 2" hole for rock bolts, average	$1,641	Dust collection system	0.0%	$0.00	$42.59	$42.59	2.6%
4	Pier holes, up to 1500 cubic yards	$1,680	Dust collection system	0.0%	$0.00	$42.59	$42.59	2.5%
5	Borings, casing borings in earth, no samples, 21/2" diameter	$1,501	Dust collection system	0.0%	$0.00	$42.59	$42.59	2.8%
Grinding and tuck pointing using hand-held tools								
6	Floors, 1/4" thick, patching concrete	$665	Dust collection system	5.0%	$33.24	$9.04	$42.28	6.4%
7	Crack repair, including chipping, sand blasting, and cleaning. Epoxy injection up to 1/4" wide.	$1,631	Dust collection system	5.0%	$72.76	$10.05	$82.81	5.1%
8	Cut and repoint brick, hard mortar, common bond.	$385	Dust collection system	5.0%	$18.30	$4.79	$23.09	6.0%

Table 4-6

Incremental Control Costs as a Percentage of Activity Costs

	Task Category/ Task Description	Total Daily Baseline Cost	Controls	Productivity Penalty	Incremental Labor Cost/Day	Incremental Equipment Cost/Day	Total Incremental Cost/Day	Total Incremental Costs as % of Baseline Costs
Heavy construction equipment operating								
9	Backfill, structural, from existing stockpile, no compaction, 50' haul, sand and gravel	$1,171	Enclosed cab with ventilation	0.0%	$0.00	$10.41	$10.41	0.9%
Hole drilling using held-held drills								
10	Drilling for anchors, up to 4" in diameter including bit and layout in concrete or brick walls, no anchor. 3/4" diameter	$371	Dust Shroud Vacuum system	2.0%	$7.30	$4.63	$11.92	3.2%
Impact drilling								
11	Drilling bituminous material, with hand-held air equipment, up to 6 inches thick	$1,965	Wet method	3.0%	$54.11	$20.59	$74.70	3.8%
12	Cutout demolition, elevated slab, bar reinforced, under 6 c.f.	$1,613	Wet method	3.0%	$43.66	$20.59	$64.25	4.0%
13	Remove masonry walls, block, solid (presumed indoor environment)	$2,700	Dust collection system	5.0%	$109.52	$9.38	$118.90	4.4%
Masonry cutting using portable saws								
14	Demolition, concrete slabs, mesh reinforcing, up to 3" deep	$1,248	Baseline includes control measures	2.0%	$12.69	$0.00	$12.69	1.0%
15	Saw cutting, brick or masonry, with hand-held saw, per inch of depth	$353	Wet method	2.0%	$5.72	$0.90	$6.62	1.9%

Table 4-6

Incremental Control Costs as a Percentage of Activity Costs

Task Category/ Task Description	Total Daily Baseline Cost	Controls	Productivity Penalty	Incremental Labor Cost/Day	Incremental Equipment Cost/Day	Total Incremental Cost/Day	Total Incremental Costs as % of Baseline Costs
16 Saw cutting, concrete walls, hydraulic saw, plain, per inch of depth	$1,191	Baseline includes control measures	2.0%	$12.69	$0.00	$12.69	1.1%
Masonry cutting using stationary saws							
17 Sawing brick or block, per inch in depth	$366	Wet method	2.0%	$7.32	$0.00	$7.32	2.0%
Milling using portable or mobile machines							
18 Asphalt cold planing & cleaning, 1" to 3" asphalt, over 25,000 SY	$5,201	Baseline includes control measures	2.0%	$45.44	$0.00	$45.44	0.9%
19 Concrete surface repair	$651	Wet methods	2.0%	$11.94	$8.70	$20.65	3.2%
20 Hand-held milling, wall grinding	$315	Dust control	5.0%	$5.72	$4.46	$10.18	3.2%
Rock crushing machine tending							
21 Rock crushing, excavation projects	$5,412	Setup and operate foam dust suppression system	0.0%	$0.00	$170.79	$170.79	3.2%
Underground (tunnel) construction work							
22 Tunnel construction, bored tunnels including mucking, 20' in diameter, rock excavation (average cost; assumes 400 feet/day)	$86,000	Additional maintenance	0.0%	$0.00	$10.07	$10.07	0.012%

Source: ERG estimates based on Tables 4-1 and 4-4.

Table 4-7

Cost Impact Summary, by Job Category

	Job Category/Description	Controls	Relative Frequency Within Categories	Labor Costs as % of Project Costs	Incremental Costs as % of Baseline Costs
Drywall finishers					
1	Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished	Dust collection system	20.0%	100.0%	5.1%
2	Drywall, gypsum plasterboard, nailed or screwed to studs, 5/8" thick, taped and finished (Identical job w/different control)	Use non-silica finishing compound	80.0%	100.0%	0.0%
	Job category total, averages		100.0%	100.0%	1.0%
Earth drillers					
3	Drilling only, 2" hole for rock bolts, average	Dust collection system	33.3%	57.6%	2.6%
4	Pier holes, 1500 cubic yards of media removed	Dust collection system	33.3%	56.3%	2.5%
5	Borings, casing borings in earth, no samples, 2.5" diameter	Dust collection system	33.3%	57.2%	2.8%
	Job category total, averages		100%	57.0%	2.7%
Grinders and tuck pointers using hand-held tools					
6	Floors, 1/4" thick, patching concrete	Dust collection system	33.3%	100.0%	6.4%
7	Crack repair, including chipping, sand blasting, and cleaning. Epoxy injection up to 1/4" wide.	Dust collection system	33.3%	89.2%	5.1%
8	Cut and repoint brick, hard mortar, common bond.	Dust collection system	33.3%	95.0%	6.0%
	Job category total, averages		100.0%	94.7%	5.8%
Heavy construction equipment operating					
9	Backfill, structural, from existing stockpile, no compaction, 50' haul, sand and gravel	Enclosed cab with ventilation	100.0%	43.6%	0.9%

Table 4-7

Cost Impact Summary, by Job Category

	Job Category/Description	Controls	Relative Frequency Within Categories	Labor Costs as % of Project Costs	Incremental Costs as % of Baseline Costs
Hole drillers using held-held drills					
10	Drilling for anchors, up to 4" in diameter including bit and layout in concrete or brick walls, no anchor. 3/4" diameter	Dust Shroud Vacuum system	100.0%	98.3%	3.2%
Impact drillers					
11	Drilling bituminous material, with hand-held air equipment, up to 6 inches thick	Wet methods	40.0%	91.8%	3.8%
12	Cutout demolition, elevated slab, bar reinforced, under 6 c.f.	Wet methods	40.0%	90.2%	4.0%
13	Remove masonry walls, block, solid (indoor environment)	Dust collection system	20.0%	81.1%	4.4%
	Job category total, averages		100%	89.0%	4.0%
Masonry cutters using portable saws					
14	Demolition, concrete slabs, mesh reinforcing, up to 3" deep	Baseline includes control measures	33.3%	50.8%	1.0%
15	Saw cutting, brick or masonry, with hand-held saw, per inch of depth	Wet method	33.3%	81.1%	1.9%
16	Saw cutting, concrete walls, hydraulic saw, plain, per inch of depth	Baseline includes control measures	33.3%	53.3%	1.1%
	Job category total, averages		100.0%	61.7%	1.3%
Masonry cutters using stationary saws					
17	Sawing brick or block, per inch in depth	Wet method	100.0%	100.0%	2.0%
Millers using portable or mobile machines					
18	Asphalt cold planing & cleaning, 1" to 3" asphalt, over 25,000 SY	Baseline includes control measures	20.0%	43.7%	0.9%
19	Concrete surface repair	Wet methods	40.0%	91.7%	3.2%

Table 4-7

Cost Impact Summary, by Job Category

Job Category/Description		Controls	Relative Frequency Within Categories	Labor Costs as % of Project Costs	Incremental Costs as % of Baseline Costs
20	Hand-held milling, wall grinding	Dust control	40.0%	90.8%	3.2%
	Job category total, averages		100.0%	45.1%	1.5%
Rock crushing machines and tenders					
21	Rock crushing, excavation projects	Wet methods	100.0%	42.0%	3.2%
Underground (tunnel) construction workers					
22	Tunnel construction, bored tunnels including mucking, 20' in diameter , rock excavation (average cost; assumes 100 feet/day)	Additional maintenance of dust suppression equipment	100.0%	15.0%	0.012%

incremental job costs over the job in each category (e.g., drywall finishers, etc.). These control costs range from 0 percent of the baseline for those jobs where baseline activities incorporate the relevant controls (such as use of non-silica drywall finishing compound) to 5 and 6 percent where LEV systems are needed for grinding and tuck-pointing tasks. As is evident from these estimates, the magnitude of the productivity impacts can substantially change the overall cost increase associated with the controls.

As noted, Table 4-7 presents the weighted average control costs, by task category. ERG defined weights for each job category based on the forecasted relative applicability of the controls and/or tasks within each category as discussed in the technological feasibility section of this report. For example, ERG estimated that impact drillers could use wet methods for most (80 percent) jobs, but that LEV would be required for 20 percent. This estimate is based on the technological feasibility analysis for impact drillers. These percentages then define the relative frequency of application for the controls that have been specified (and which are summarized in Table 4-6).

The table also presents the weighted average of the labor costs (with controls) of the total project costs. This value is significant to the calculations because it is used to aggregate costs to the national level as detailed in Section 4.6.

4.6 AGGREGATE TECHNICAL COMPLIANCE COSTS

4.6.1 Methodological Overview

ERG used the weighted average controls costs and labor share of projects shown in Table 4-7 to extrapolate task-specific crew costs into estimates of the aggregate value of silica-related projects. ERG first estimated, on an annual basis, the amount of time workers might spend on projects corresponding to each task category. Using wage and employment data from the BLS, Occupational Employment Survey (OES), ERG then estimated the full-time equivalent number of such employees and the associated value of their work.[1] Next, ERG used the average labor share of value for each task category to estimate the total

[1] Bureau of Labor Statistics, Occupational Employment Survey, 2000. ERG benchmarked the OES employment statistics to County Business Pattern industry totals for 2000 to ensure consistency of employment estimates.

annual value of silica-related tasks.[2] The value of projects requiring additional controls was estimated by multiplying the total value by the percentage of workers who are exposed at levels higher than the PEL (see Table 3-2). ERG then multiplied these values by the percentage changes in baseline costs due to required additional controls (shown in Table 4-7) to generate estimates of total compliance costs.

4.6.2 Aggregate Labor Costs for Representative Projects

To estimate aggregate labor costs or value for each task category, ERG first matched OES occupational classifications with the labor requirements for each task category. These matching occupations are shown in Table 4-8. In order to estimate the percentage of time workers spend on the relevant tasks, ERG designated some occupations as "key" and others as "secondary." The distinction is needed in order to estimate the amount of time workers participate in silica generating tasks.

4.6.2.1 Key and Secondary Occupations

Key occupations represent the worker or workers on each crew who perform the principal silica-generating activity in each task. ERG judged, for example, that drillers represent the key occupation for the earth drilling tasks outlined in the analysis. Earth drillers spend an estimated 75 percent of their time performing relevant drilling tasks, such as those that generate silica exposures. In other cases, the activities of those in key occupations are less closely correlated with the task. For example, the key occupation for impact drilling was judged to be construction laborers. This group performs many diverse construction tasks, and ERG estimated that the time spent on impact drilling was approximately 3 percent.

Other, "secondary" crew members (e.g., the foreman) were estimated in terms of their ratio to the number of key workers. As noted above, ERG used these percentages and ratios to estimate (on an annual basis) the amount of time these employees are engaged in and around task-related work that causes silica exposures. The estimate of the percent of time performing the silica-generating task can be viewed in terms

[2] Dividing project labor value by the labor share of project value yields an estimate of total value.

Table 4-8

Key and Secondary Occupations, by Task Category

Task Category/Occupations/Industries	Pecentage in Key Occupations Working on Task (Full-Time Equivalent)	Ratio of Secondary to Key Workers
Drywall Finishing		
Key Occupation(s):		
Drywall and Ceiling Tile Installers	25.0%	
Tapers	25.0%	
Secondary Occupation(s):		
None		NA
Earthdrilling		
Key Occupation(s):		
Earth Drillers, Except Oil and Gas	75.0%	
Secondary Occupation(s):		
First-Line Supervisors/Managers of Construction Trades and Extraction Workers		0.50
Construction Laborers		1.00
Operating Engineers and Other Construction Equipment Operators		1.00
Explosives Workers, Ordnance Handling Experts, and Blasters		0.25
Helpers–Extraction Workers		0.25
Grinding and Tuckpointing		
Key Occupation(s):		
Brickmasons and Blockmasons	2.5%	
Cement Masons and Concrete Finishers	2.5%	
Helpers--Brickmasons, Blockmasons, Stonemasons, and Tile and Marble Setters	2.5%	
Secondary Occupation(s):		
First-Line Supervisors/Managers of Construction Trades and Extraction Workers		1.0
Construction Laborers		3.0
Heavy Construction Equipment Operators		
Key Occupation(s):		
Operating Engineers and Other Construction Equipment Operators	75.0%	
Excavating and Loading Machine and Dragline Operators	50.0%	
Secondary Occupation(s):		
Construction Laborers		0.5
Hole Drillers Using Hand-Held Drills		
Key Occupation(s):		
Carpenters	1.0%	
Helpers--Carpenters	1.0%	
Secondary Occupation(s):		
Construction Laborers		1.0
Impact Drilling		
Key Occupation(s):		
Construction Laborers	3.0%	
Secondary Occupation(s):		
First-Line Supervisors/Managers of Construction Trades and Extraction Workers		0.25
Operating Engineers and Other Construction Equipment Operators		0.25

Table 4-8

Key and Secondary Occupations, by Task Category

Task Category/Occupations/Industries	Pecentage In Key Occupations Working on Task (Full-Time Equivalent)	Ratio of Secondary to Key Workers
Masonry cutters using portable saws		
Key Occupation(s):		
Brickmasons and Blockmasons	10.0%	
Stonemasons	10.0%	
Helpers--Brickmasons, Blockmasons, Stonemasons, and Tile and Marble Setters	10.0%	
Secondary Occupation(s):		
Construction Laborers		1.0
Masonry cutters using stationary saws		
Key Occupation(s):		
Brickmasons and Blockmasons	10.0%	
Stonemasons	10.0%	
Helpers--Brickmasons, Blockmasons, Stonemasons, and Tile and Marble Setters	10.0%	
Secondary Occupation(s):		
None		NA
Millers Using Portable or Mobile Machines		
Key Occupation(s):		
Cement Masons and Concrete Finishers	5.0%	
Paving, Surfacing, and Tamping Equipment Operators	5.0%	
Secondary Occupation(s):		
First-Line Supervisors/Managers of Construction Trades and Extraction Workers		0.67
Construction Laborers		1.00
Rockcrushing		
Key Occupation(s):		
Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	75.0%	
Secondary Occupation(s):		
First-Line Supervisors/Managers of Construction Trades and Extraction Workers		0.33
Construction Laborers		1.00
Underground construction (tunnel) work		
Key Occupation(s):		
Tunnel Workers [a]	50.0%	

Note: Occupations based on BLS, Occupational Employment Survey classification system.
[a] Tunnel workers not identfied by specific occupational title.

of the full-time equivalent employees engaged in each task category. These estimates and the corresponding ratios for secondary workers are shown in Table 4-8.

For the key occupations, ERG was able to estimate with some confidence (although in the context of limited data) the share of time workers perform silica-generating tasks. For the secondary occupations, such estimates were generally not possible. Thus, their participation in silica-generating tasks was defined based on their relationship to the key occupations. This participation is defined by the presence in the job crews, as defined in Table 4-1. To illustrate the need for this approach, consider the difficulty in predicting how often construction foremen of all types are present during silica-generating tasks. BLS data, for example, provides only a total number of foremen, but no information about how they might spend their time. It is reasonable to forecast, however, using the job crew definitions, that foremen will be present in some proportion to the specific impact drilling, earth drilling, and other silica-generating tasks performed by the key occupational groups. Thus, ERG used estimates of occupational activities that could reasonably be developed as the basis for making estimates that could not otherwise be developed.

To illustrate the use of these estimates for specific tasks, e.g., impact drilling, the construction laborer is the key occupation and first-line supervisors and equipment operators are the secondary occupations. Because the relevant standard work crew (specified in the R.S. Means Construction Guide) consists of a supervisor, an equipment operator, and four construction laborers, ERG used a ratio of 1 to 4 (0.25, as shown in the table) to estimate the participation level for each of these secondary occupations. In another example, ERG estimated that construction laborers are a secondary occupation and heavy equipment operators are the key occupation for standard work crews involving such equipment. The standard work crew in R.S. Means calls for a heavy equipment operator and 0.5 construction laborers. Thus, ERG assumed that 0.5 construction laborers participate in tasks involving heavy equipment operations.

For some activities, the crew size and make-up vary among the jobs defined in the activity category. In these cases, ERG judged the most representative crew composition and used that to define the ratio of secondary to key occupations.

ERG's estimates of the full-time equivalent employees performing the silica-generating tasks are one of many influences on the final cost estimates. There is little data, however, on the breakdown of time spent by construction workers in various activities. The following discussion presents ERG's basis for the time-on-task estimates for the key occupations.

Drywall finishers. Workers who perform drywall finishing typically divide their time between drywall installation, finishing, and cleanup tasks. Of these, finishing is judged to require less than one-quarter of the job time.

Earth drillers. A review of NIOSH reports covering earth drillers showed that over 75% of drillers' time was spent on actual drilling. (NIOSH 1992a, 1992b, 1995; NIOSH ECTB 233-122c, 1999). ERG used 75 percent as the best indication of the time spent on the dust-generating task for this group.

Grinding and tuckpointing. Grinding and tuckpointing are only two of the numerous jobs performed by brickmasons, cement masons, and their helpers. Bricklaying, cement, and masonry construction tasks are much more common. Where grinding and tuckpointing tasks are being performed, ERG's review of the OSHA SEP reports indicated that the time spent on these tasks varied widely (See the technological feasibility analysis for this activity in Section Three). ERG estimated that 2.5 percent of time for each of the relevant operations would be spent on these tasks.

Heavy construction equipment operating. Heavy equipment operators often spend the bulk of their work shift on the equipment, engaged in construction work. OSHA Inspection Reports and other studies consistently show that heavy equipment operators perform their tasks for more than 7 hours per shift (OSHA SEP Inspection Reports 122212079, 116179359; Greenspan, et al., 1995; NIOSH HETA 93-0696-2395, 1999, ECTB 233-122c, 1999, ECTB 233-120, 1999c.). Nevertheless, this occupational category also includes operators of such equipment as pile drivers, cranes, and air compressors that are not generally associated with silica dust generation. ERG used an estimate of 75 percent for operating engineers and 50 percent for excavating and loading machine and dragline operators in this category to reflect the extent of relevant heavy equipment operations.

Hole drilling. While many workers might occasionally be assigned to drill holes in concrete, this activity represents a very small part of the activities of the large occupational groups performing this work. ERG judged that one percent of time for carpenters and carpenter's assistants in the affected industries is spent in hole drilling.

Impact drilling. ERG judged that among the key occupation, construction laborers, relatively few are engaged in impact drilling. ERG examined a snapshot of construction activities from the OSHA publication, *Injuries to Construction Laborers* (BLS, 1986). That source presents a survey of injured construction workers and includes questions about their activities at the time they were injured. The survey indicated that 3 percent of construction workers were using jackhammers at the time they were injured. ERG judged that, while the survey was not intended to characterize typical construction activities, and a survey of injured workers introduces considerable potential bias into the observations, this estimate was useful as an observation of representative construction activities. ERG also judges that, because jackhammers are more heavy, cumbersome, and powerful than much construction equipment, workers are probably injured more frequently while using jackhammers on average, than when using all other construction equipment. Thus, the 3 percent figure is likely to be an upper bound of the amount of time spent on impact drilling. In lieu of other data, ERG assumed that 3 percent of laborers are performing this task.

Masonry cutting using portable saws. The key occupations for masonry cutting, namely brickmasons, blockmasons, stonemasons, and their helpers, spend a small share of their time on average cutting. According to OSHA and NIOSH reports, saw operators perform multiple masonry activities and might engage in cutting for only a small portion of their shift (OSHA SEP Inspection Report 300646510; NIOSH ECTB 233-118c, 1999). Another glimpse of this activity can be gleaned from the BLS injury report for construction laborers which reported that 3 percent of workers injured were "breaking up or cutting concrete, asphalt, brick, rocks, etc., at the time of their injury." (This data is of uncertain value since it probably excludes most craft workers (i.e., masons), and various other potential biases in injury data.) ERG estimated that 10 percent of time for each of the relevant occupations would be spent on these tasks.

Masonry cutting using stationary saws. As noted above, OSHA and NIOSH reports indicate that saw operators perform multiple masonry activities and might engage in cutting for only a small portion of their shift (OSHA SEP Inspection Report 300646510; NIOSH ECTB 233-118c, 1999). ERG estimated that the relevant mason occupations spend 10 percent of their time on cutting tasks.

Milling using portable or mobile machines. Milling represents a small share of the overall job duties of the relevant key occupations, cement masons and paving, surfacing and tamping equipment operators. ERG judged that 5 percent of all work for these occupations is spent in milling tasks.

Rockcrushers. According to information collected from personal communication and OSHA SEP inspection reports, rock crushing machine operators spend most, if not all, of their shift at and around the rock crushing process (Polhemus, 2000; Haney, 2001; OSHA SEP Inspection Report 2116507; OSHA SEP Inspection Report 300441862.) ERG estimated that this occupational group spends 75 percent of its time on the rock crushing task.

Underground (tunnel) construction workers. Underground workers perform both tunnel work and other types of construction work. ERG estimated that underground workers participate in underground work approximately 50 percent of the time. (This level of work also generates estimates, as described further below, of the labor value of tunneling work that are approximately consistent with the level of work measured in Census estimates.)

Table 4-9 shows estimates of the full-time equivalent number of key and secondary workers, by occupation, for each task category using the percentages and ratios from Table 4-8. Table 4-10 shows the corresponding estimates on an industry basis.[3] Overall, a full-time equivalent of 463,500 workers are estimated to work on silica-related tasks, ranging from 15,600 for hole drilling to 250,000 for heavy construction equipment operations

[3] ERG notes that some industries appear unlikely to generate silica exposures even when the affected occupational categories are included within their employment totals. Despite this, ERG has not eliminated these industries from consideration on the grounds that some establishments might participate substantially in more than one type of construction activity, a fact which might not be fully represented by the NAICS classification. Further, eliminating these industries created accounting and estimation difficulties for the analysis.

Table 4-9

Full-Time Equivalent Employees Working on At-Risk Tasks, by Occupation

Occupation	Total Employment	Total Full-Time Equivalent Working on At-Risk Tasks		Full-Time Equivalent Working on At-Risk Tasks: Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
Employees In Key Occupations														
First-Line Supervisors/Managers of Construction Trades and Extraction Workers	364,137	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Brickmasons and Blockmasons	97,839	22,014	22.5%	0	0	2,446	0	0	0	9,784	9,784	0	0	0
Stonemasons	8,112	1,622	20.0%	0	0	0	0	0	0	811	811	0	0	0
Carpenters	686,850	6,869	1.0%	0	0	0	0	6,869	0	0	0	0	0	0
Cement Masons and Concrete Finishers	141,654	10,624	7.5%	0	0	3,541	0	0	0	0	0	7,083	0	0
Construction Laborers	682,085	20,463	3.0%	0	0	0	0	0	20,463	0	0	0	0	0
Paving, Surfacing, and Tamping Equipment Operators	37,685	1,884	5.0%	0	0	0	0	0	0	0	0	1,884	0	0
Operating Engineers and Other Construction Equipment Operators	195,126	146,344	75.0%	0	0	0	146,344	0	0	0	0	0	0	0
Drywall and Ceiling Tile Installers	113,001	28,250	25.0%	28,250	0	0	0	0	0	0	0	0	0	0
Tapers	34,778	8,695	25.0%	8,695	0	0	0	0	0	0	0	0	0	0
Helpers--Brickmasons, Blockmasons, Stonemasons, and Tile and Marble Setters	55,642	12,519	22.5%	0	0	1,391	0	0	0	5,564	5,564	0	0	0
Helpers--Carpenters	91,780	918	1.0%	0	0	0	0	918	0	0	0	0	0	0
Earth Drillers, Except Oil and Gas	9,641	7,231	75.0%	0	7,231	0	0	0	0	0	0	0	0	0
Explosives Workers, Ordnance Handling Experts, and Blasters	1,044	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Helpers--Extraction Workers	5,199	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	939	705	75.0%	0	0	0	0	0	0	0	0	0	705	0
Excavating and Loading Machine and Dragline Operators	40,584	20,292	50.0%	0	0	0	20,292	0	0	0	0	0	0	0
Tunnel workers [a]	[a]	1,331	NA	0	0	0	0	0	0	0	0	0	0	1,331
Total	2,566,094	289,780	11.3%	36,945	7,231	7,378	166,636	7,786	20,463	16,159	16,159	8,967	705	1,331
Employees In Secondary Occupations [b]														
First-Line Supervisors/Managers of Construction Trades and Extraction Workers	364,137	20,840	5.7%	0	2,205	7,378	0	0	5,116	0	0	5,918	233	0
Brickmasons and Blockmasons	97,839	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Stonemasons	8,112	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Carpenters	686,850	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Cement Masons and Concrete Finishers	141,654	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Construction Laborers	682,085	142,591	20.9%	0	3,726	22,135	83,318	7,786	0	16,159	0	8,967	705	0
Paving, Surfacing, and Tamping Equipment Operators	37,685	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Operating Engineers and Other Construction Equipment Operators	195,126	7,830	4.0%	0	3,009	0	0	0	5,116	0	0	0	0	0
Drywall and Ceiling Tile Installers	113,001	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Tapers	34,778	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Helpers--Brickmasons, Blockmasons, Stonemasons, and Tile and Marble Setters	55,642	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Helpers--Carpenters	91,780	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Earth Drillers, Except Oil and Gas	9,641	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Explosives Workers, Ordnance Handling Experts, and Blasters	1,044	657	62.9%	0	657	0	0	0	0	0	0	0	0	0
Helpers--Extraction Workers	5,199	1,808	34.8%	0	1,808	0	0	0	0	0	0	0	0	0
Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	939	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Excavating and Loading Machine and Dragline Operators	40,584	0	0.0%	0	0	0	0	0	0	0	0	0	0	0
Total	2,566,094	173,726	6.8%	0	11,406	29,513	83,318	7,786	0 10,231	16,159	0	14,885	937	0
Total for key and secondary occupations	2,566,094	463,486	18.1%	36,945	18,636	36,892	249,955	15,573	30,694	32,318	16,159	23,852	1,642	1,331

Source: Based on task percentages shown in Table 4-8.
[a] Tunnel workers not identified by specific occupational title. Tunnel worker employment included in the totals for other listed occupations.
[b] Total full-time equivalent constrained by occupational employment totals for each industry.

Table 4-10

Full-Time Equivalent Employees Working on At-Risk Tasks, by Industry

NAICS	Title	Full-Time Equivalent Working on At-Risk Tasks											
		All Tasks [a]	Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	861	0	0	4	754	29	70	0	0	4	0	0
2332	Residential building construction	25,695	1,679	0	2,880	7,146	5,826	3,933	1,296	648	2,285	0	0
2333	Nonresidential building construction	39,569	2,238	0	4,868	15,694	3,488	5,294	3,148	1,574	3,264	0	0
2341	Highway, street, bridge & tunnel construction	69,346	0	457	1,323	56,947	181	3,288	104	52	4,226	1,439	1,331
2349	Other heavy construction	99,561	119	4,828	1,028	85,697	514	5,579	298	149	1,245	104	0
2351	Plumbing, heating & AC contractors	6,336	45	0	112	5,084	97	776	108	54	60	0	0
2352	Painting & wall covering contractors	1,325	665	0	61	175	57	165	62	31	109	0	0
2353	Electrical contractors	3,141	0	0	31	2,598	36	444	0	0	33	0	0
2354	Masonry, drywall, insulation, tile contractors	90,312	30,919	0	15,785	1,631	1,019	2,293	25,029	12,515	1,022	99	0
2355	Carpentry & floor contractors	6,252	703	0	352	716	3,249	705	167	83	277	0	0
2356	Roofing, siding, & sheet metal contractors	818	59	0	0	117	260	381	0	0	0	0	0
2357	Concrete contractors	36,218	307	0	9,018	10,906	432	3,682	1,036	518	10,319	0	0
2358	Water well drilling contractors	8,179	0	8,127	4	504	0	49	0	0	4	0	0
2359	Other special trade contractors	75,872	210	5,224	1,427	61,984	384	4,034	1,071	535	1,004	0	0
	Totals	463,486	36,945	18,636	36,892	249,955	15,573	30,694	32,318	16,159	23,852	1,642	1,331

Source: Based on percentages shown in Table 4-8 and employment by industry and occupation as reported in BLS, Occupation Employment Survey, 2000 and benchmarked to industry employment totals from U.S. Bureau of Census, County Business Patterns, 2000.
[a] Total full-time equivalent constrained by occupational employment totals for each industry.

4.6.2.2 Deriving the Labor Cost and Total Value of Silica-Exposure-Generating Tasks

ERG next multiplied the mean wage, as reported by OES (for each occupation and industry shown in Tables 4-9 and 4-10) by 2,000 hours and by the number of affected full-time equivalent employees, to derive the total value of wages expended for each silica-exposure generating task. These estimates where then inflated to adjust for fringe benefits.[4] These values, totaled by industry and task category, are summarized in the top half of Table 4-11 as the annual labor value (or labor cost) of silica-generating projects.

ERG then extrapolated the labor values for each industry and task category to the total project value by dividing by the labor share of project costs. Because the labor share for each task category equals the labor value divided by project value, dividing the labor value by the labor share generates an estimate of project value. Thus for earth drilling, for example, ERG estimated the labor share of project value or cost at 57.0 percent. The total project value for these tasks was estimated, therefore, at 1.75 times the labor value (1 divided by 0.57). Table 4-11 shows the estimated labor share for each task category as derived in Table 4-7 and the associated estimates of total project value for each industry and task category. Overall, ERG estimated the value of silica-generating tasks at $40.1 billion. The values for specific task categories ranged from $169.7 million for rock crushing to $26.9 billion for heavy construction equipment operations.

4.7 AGGREGATE TECHNICAL CONTROL COSTS

Table 4-12 shows the percentage of workers requiring controls for each of three PEL options. These figures are the percentage of workers for each task category estimated to be exposed at levels above the PEL. ERG multiplied these percentages by the total project values for each task category to derive the value of silica-generating projects for which additional controls are required. Tables 4-13, 4-15, and 4-17 show these values for each of the regulatory options. For the PEL option of 50 $\mu g/m^3$, for example, $11.0

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[4] Bureau of Labor Statistics, Employer Costs for Employee Compensation, 2000. For private sector, construction industry employees, wages and salaries comprised 71.1 percent of total compensation in 2000.

Table 4-11

Value of At-Risk Tasks ($millions)

NAICS	Title	All Tasks	At-Risk Tasks: Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
Labor Value of At-Risk Tasks [a]													
2331	Land subdivision & land development	$34.7	$0.0	$0.0	$0.2	$30.4	$1.1	$2.9	$0.0	$0.0	$0.2	$0.0	$0.0
2332	Residential building construction	$1,100.0	$81.6	$0.0	$115.2	$338.3	$223.7	$164.4	$52.8	$31.1	$92.8	$0.0	$0.0
2333	Nonresidential building construction	$1,848.3	$106.6	$0.0	$220.5	$760.2	$152.3	$241.1	$136.8	$77.3	$153.6	$0.0	$0.0
2341	Highway, street, bridge & tunnel construction	$3,409.4	$0.0	$22.9	$62.0	$2,821.6	$8.3	$156.3	$4.6	$2.5	$203.1	$62.6	$65.6
2349	Other heavy construction	$4,555.0	$4.5	$221.1	$44.8	$3,939.3	$22.4	$240.8	$13.5	$8.1	$56.2	$4.3	$0.0
2351	Plumbing, heating & AC contractors	$298.5	$2.2	$0.0	$5.2	$240.6	$4.2	$35.3	$5.0	$3.0	$2.9	$0.0	$0.0
2352	Painting & wall covering contractors	$60.9	$32.0	$0.0	$2.7	$7.6	$2.2	$6.5	$3.3	$2.3	$4.4	$0.0	$0.0
2353	Electrical contractors	$160.7	$0.0	$0.0	$1.4	$134.9	$1.5	$21.2	$0.0	$0.0	$1.6	$0.0	$0.0
2354	Masonry, drywall, insulation, tile contractors	$4,192.2	$1,531.8	$0.0	$713.7	$81.6	$46.9	$104.2	$1,066.1	$594.4	$49.1	$4.3	$0.0
2355	Carpentry & floor contractors	$265.4	$42.6	$0.0	$15.3	$27.6	$129.0	$28.5	$5.8	$2.9	$13.9	$0.0	$0.0
2356	Roofing, siding, & sheet metal contractors	$32.0	$1.8	$0.0	$0.0	$5.5	$9.8	$15.0	$0.0	$0.0	$0.0	$0.0	$0.0
2357	Concrete contractors	$1,607.6	$12.4	$0.0	$382.0	$515.3	$18.1	$158.7	$40.2	$21.4	$459.6	$0.0	$0.0
2358	Water well drilling contractors	$355.2	$0.0	$330.9	$0.1	$22.0	$0.0	$2.0	$0.0	$0.0	$0.2	$0.0	$0.0
2359	Other special trade contractors	$3,480.8	$9.0	$246.0	$64.2	$2,841.1	$16.1	$176.9	$50.6	$30.6	$46.3	$0.0	$0.0
	Totals	$21,400.6	$1,824.4	$821.0	$1,627.2	$11,765.9	$635.6	$1,353.7	$1,378.6	$773.5	$1,083.8	$71.2	$65.6
Average Labor Share of Project Value [b]			100.0%	57.0%	94.7%	43.6%	98.3%	89.0%	61.7%	100.0%	45.1%	42.0%	15.0%
Total Value of At-Risk Tasks [c]													
2331	Land subdivision & land development	$74.5	$0.0	$0.0	$0.2	$69.6	$1.1	$3.2	$0.0	$0.0	$0.4	$0.0	$0.0
2332	Residential building construction	$1,713.8	$81.6	$0.0	$121.6	$775.8	$227.5	$184.6	$85.5	$31.1	$206.0	$0.0	$0.0
2333	Nonresidential building construction	$3,148.0	$106.6	$0.0	$232.7	$1,743.2	$154.9	$270.7	$221.5	$77.3	$340.9	$0.0	$0.0
2341	Highway, street, bridge & tunnel construction	$7,806.9	$0.0	$40.2	$65.4	$6,470.2	$8.4	$175.5	$7.5	$2.5	$450.7	$149.1	$437.4
2349	Other heavy construction	$9,931.1	$4.5	$387.7	$47.2	$9,033.4	$22.8	$270.4	$21.9	$8.1	$124.7	$10.3	$0.0
2351	Plumbing, heating & AC contractors	$620.9	$2.2	$0.0	$5.5	$551.7	$4.3	$39.7	$8.1	$3.0	$6.4	$0.0	$0.0
2352	Painting & wall covering contractors	$79.1	$32.0	$0.0	$2.8	$17.5	$2.2	$7.3	$5.3	$2.3	$9.7	$0.0	$0.0
2353	Electrical contractors	$339.9	$0.0	$0.0	$1.5	$309.4	$1.5	$23.8	$0.0	$0.0	$3.6	$0.0	$0.0
2354	Masonry, drywall, insulation, tile contractors	$5,077.9	$1,531.8	$0.0	$753.4	$187.1	$47.7	$117.1	$1,727.1	$594.4	$109.0	$10.3	$0.0
2355	Carpentry & floor contractors	$328.0	$42.6	$0.0	$16.1	$63.2	$131.2	$32.0	$9.3	$2.9	$30.7	$0.0	$0.0
2356	Roofing, siding, & sheet metal contractors	$41.1	$1.8	$0.0	$0.0	$12.5	$10.0	$16.8	$0.0	$0.0	$0.0	$0.0	$0.0
2357	Concrete contractors	$2,900.1	$12.4	$0.0	$403.2	$1,181.5	$18.4	$178.2	$65.1	$21.4	$1,019.8	$0.0	$0.0
2358	Water well drilling contractors	$633.6	$0.0	$580.3	$0.2	$50.5	$0.0	$2.2	$0.0	$0.0	$0.4	$0.0	$0.0
2359	Other special trade contractors	$7,453.5	$9.0	$431.4	$67.7	$6,515.0	$16.4	$198.7	$81.9	$30.6	$102.7	$0.0	$0.0
	Totals	$40,148.5	$1,824.4	$1,439.6	$1,717.6	$26,980.8	$646.6	$1,520.2	$2,233.4	$773.5	$2,405.2	$169.7	$437.4

[a] Based on average wage as reported by BLS, Occupational Employment Survey, 2000 for occupations and industries shown in Table 4-8. Wages inflated to account for fringe benefits as reported by BLS, Employer Costs for Employee Compensation, 2000. Assumes 2000 hours of employment per year.
[b] See Table 4-7.
[c] Calculated by dividing the labor value of each at-risk task by the corresponding average labor share of project value.

Table 4-12

Percentage of Workers Requiring Controls

	PEL Option (Micrograms per Cubic Meter)		
Task Category	**50**	**75**	**100**
Drywall finishers	6.7%	0.0%	0.0%
Earth drillers	50.0%	40.0%	33.3%
Grinders and tuck pointers using hand-held tools	93.2%	89.9%	82.4%
Heavy construction equipment operators	16.7%	12.5%	8.3%
Hole drillers using held-held drills	55.6%	11.1%	11.1%
Impact drillers	79.0%	71.0%	62.0%
Masonry cutters using stationary saws	47.3%	43.2%	39.2%
Masonry cutters using portable saws	33.3%	33.3%	16.7%
Millers using portable or mobile machines	53.6%	46.4%	28.6%
Rock crushing machines and tenders	100.0%	100.0%	100.0%
Underground construction (tunnel) work	20.0%	13.3%	10.0%

Source: Table 3-2.

billion in silica-generating construction projects will require controls. Approximately forty percent of these costs are generated by additional controls for heavy equipment operators.

ERG next multiplied the resultant task value figures by industry with the incremental cost percentage for each task to derive the aggregate incremental compliance cost estimates. These cost impact percentages were derived in Table 4-7. Using the drywall task as an example, projects requiring additional controls are estimated to incur a 1.0 percent increase in total cost. For a PEL of 50 $\mu g/m^3$, the total value of drywall finishing tasks requiring controls is estimated at $5.4 million per year in the residential building construction industry (NAICS 2332). The incremental cost of silica controls in this industry per year is thus $5.4 million times 1 percent or approximately $54,000 per year. These calculations are performed for each of the three PEL options of 50, 75, or 100 $\mu g/m^3$. The results are shown Tables 4-14, 4-16, and 4-18, respectively. For a PEL of 50 $\mu g/m^3$, total compliance costs for controls are estimated at $244.7 million. For PELs of 75 $\mu g/m^3$ and 100 $\mu g/m^3$, compliance costs fall to $210.8 million and $176.7 million, respectively.

The aggregate compliance cost tables also indicate the distribution of compliance costs by task category, as indicated in Tables 4-14, 4-16, and 4-18. For Table 4-14 (PEL of 50 $\mu g/m^3$), the largest share of compliance costs, roughly 38 percent, is forecast for the grinding and tuckpointing tasks. As described in the exposure and technological feasibility section, these jobs are particularly dusty and the best available control methods (LEV) require some extra time to be used effectively. (ERG estimated that the use of dust control equipment would impose a 5 percent productivity on these tasks.) Impact drilling tasks and heavy equipment operations are forecast to generate the next highest compliance costs. A relatively large percentage of impact drillers require additional controls, while heavy equipment operations comprise the largest share of total project value.

Tables 4-14, 4-16, and 4-18 also indicate the distribution of compliance costs across NAICS industries. For the PEL of 50 $\mu g/m^3$, masonry, drywall, insulation, and tile contractors (NAICS 2354) will incur the highest costs at over $62 million per year. Concrete contractors and other heavy construction are forecast to also to have relatively high cost totals. Masonry and concrete contractors both incur costs principally to control grinding and tuckpointing operations.

Table 4-13

Total Value of At-Risk Tasks Requiring Controls ($millions): PEL = 50 Micrograms per Cubic Meter

			At-Risk Tasks										
NAICS	Title	All Tasks	Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	$15.06	$0.00	$0.00	$0.16	$11.60	$0.62	$2.55	$0.00	$0.00	$0.13	$0.00	$0.00
2332	Residential building construction	$646.19	$5.44	$0.00	$113.41	$129.30	$126.41	$145.85	$40.46	$16.66	$68.67	$0.00	$0.00
2333	Nonresidential building construction	$1,074.44	$7.11	$0.00	$216.99	$290.54	$86.08	$213.88	$104.78	$41.42	$113.64	$0.00	$0.00
2341	Highway, street, bridge & tunnel construction	$1,694.46	$0.00	$20.09	$60.99	$1,078.37	$4.67	$138.63	$3.55	$1.32	$150.24	$149.12	$87.49
2349	Other heavy construction	$2,036.61	$0.30	$193.87	$44.05	$1,505.57	$12.65	$213.62	$10.37	$4.34	$41.57	$10.27	$0.00
2351	Plumbing, heating & AC contractors	$138.54	$0.15	$0.00	$5.15	$91.95	$2.38	$31.33	$3.82	$1.61	$2.15	$0.00	$0.00
2352	Painting & wall covering contractors	$21.65	$2.13	$0.00	$2.64	$2.92	$1.25	$5.75	$2.51	$1.21	$3.25	$0.00	$0.00
2353	Electrical contractors	$73.84	$0.00	$0.00	$1.41	$51.57	$0.85	$18.81	$0.00	$0.00	$1.20	$0.00	$0.00
2354	Masonry, drywall, insulation, tile contractors	$2,136.72	$102.12	$0.00	$702.45	$31.19	$26.52	$92.48	$816.89	$318.41	$36.34	$10.32	$0.00
2355	Carpentry & floor contractors	$142.76	$2.84	$0.00	$15.02	$10.53	$72.90	$25.25	$4.41	$1.56	$10.25	$0.00	$0.00
2356	Roofing, siding, & sheet metal contractors	$21.03	$0.12	$0.00	$0.00	$2.09	$5.55	$13.27	$0.00	$0.00	$0.00	$0.00	$0.00
2357	Concrete contractors	$1,106.92	$0.83	$0.00	$375.97	$196.92	$10.22	$140.80	$30.78	$11.45	$339.95	$0.00	$0.00
2358	Water well drilling contractors	$300.61	$0.00	$290.17	$0.15	$8.41	$0.00	$1.76	$0.00	$0.00	$0.12	$0.00	$0.00
2359	Other special trade contractors	$1,620.75	$0.60	$215.69	$63.17	$1,085.84	$9.13	$156.94	$38.76	$16.40	$34.23	$0.00	$0.00
		$11,029.60	$121.63	$719.82	$1,601.57	$4,496.80	$359.21	$1,200.94	$1,056.32	$414.38	$801.73	$169.71 9	$87.49

Source: Calculated by mulitplying the total value of each at-risk task by the percentage of workers requiring controls. See Table 4-12.

Table 4-14

Compliance Costs ($millions): PEL = 50 Micrograms per Cubic Meter

NAICS	Title	All Tasks	At-Risk Tasks: Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	$0.24	$0.00	$0.00	$0.01	$0.10	$0.02	$0.10	$0.00	$0.00	$0.00	$0.00	$0.00
2332	Residential building construction	$19.34	$0.06	$0.00	$6.59	$1.15	$4.06	$5.83	$0.41	$0.33	$0.92	$0.00	$0.00
2333	Nonresidential building construction	$29.98	$0.07	$0.00	$12.61	$2.58	$2.77	$8.55	$1.06	$0.83	$1.52	$0.00	$0.00
2341	Highway, street, bridge & tunnel construction	$26.06	$0.00	$0.44	$3.54	$9.59	$0.15	$5.54	$0.04	$0.03	$2.01	$4.71	$0.01
2349	Other heavy construction	$30.23	$0.00	$4.26	$2.56	$13.39	$0.41	$8.54	$0.10	$0.09	$0.56	$0.32	$0.00
2351	Plumbing, heating & AC contractors	$2.55	$0.00	$0.00	$0.30	$0.82	$0.08	$1.25	$0.04	$0.03	$0.03	$0.00	$0.00
2352	Painting & wall covering contractors	$0.56	$0.02	$0.00	$0.15	$0.03	$0.04	$0.23	$0.03	$0.02	$0.04	$0.00	$0.00
2353	Electrical contractors	$1.34	$0.00	$0.00	$0.08	$0.46	$0.03	$0.75	$0.00	$0.00	$0.02	$0.00	$0.00
2354	Masonry, drywall, insulation, tile contractors	$62.09	$1.04	$0.00	$40.81	$0.28	$0.85	$3.69	$8.23	$6.37	$0.49	$0.33	$0.00
2355	Carpentry & floor contractors	$4.56	$0.03	$0.00	$0.87	$0.09	$2.34	$1.01	$0.04	$0.03	$0.14	$0.00	$0.00
2356	Roofing, siding, & sheet metal contractors	$0.73	$0.00	$0.00	$0.00	$0.02	$0.18	$0.53	$0.00	$0.00	$0.00	$0.00	$0.00
2357	Concrete contractors	$34.65	$0.01	$0.00	$21.85	$1.75	$0.33	$5.63	$0.31	$0.23	$4.56	$0.00	$0.00
2358	Water well drilling contractors	$6.54	$0.00	$6.38	$0.01	$0.07	$0.00	$0.07	$0.00	$0.00	$0.00	$0.00	$0.00
2359	Other special trade contractors	$25.82	$0.01	$4.74	$3.67	$9.66	$0.29	$6.27	$0.39	$0.33	$0.46	$0.00	$0.00
	Totals	$244.67	$1.24	$15.83	$93.06	$39.99	$11.54	$47.98	$10.64	$8.29	$10.75	$5.36	$0.01

Source: Calculated by multiplying the value of each at-risk task requiring controls by the percentage increase in project controls due to addtional dust controls. See Table 4-7.

Table 4-15

Total Value of At-Risk Tasks Requiring Controls ($millions): PEL = 75 Micrograms per Cubic Meter

NAICS	Title	All Tasks	At-Risk Tasks										
			Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	$11.41	$0.00	$0.00	$0.15	$8.70	$0.12	$2.30	$0.00	$0.00	$0.13	$0.00	$0.00
2332	Residential building construction	$482.73	$0.00	$0.00	$109.30	$96.97	$25.28	$131.08	$36.99	$14.44	$68.67	$0.00	$0.00
2333	Nonresidential building construction	$881.81	$0.00	$0.00	$209.13	$217.90	$17.22	$192.23	$95.80	$35.90	$113.64	$0.00	$0.00
2341	Highway, street, bridge & tunnel construction	$1,371.23	$0.00	$16.07	$58.78	$808.78	$0.93	$124.59	$3.25	$1.14	$150.24	$149.12	$58.32
2349	Other heavy construction	$1,586.33	$0.00	$155.10	$42.45	$1,129.18	$2.53	$191.99	$9.48	$3.76	$41.57	$10.27	$0.00
2351	Plumbing, heating & AC contractors	$109.59	$0.00	$0.00	$4.97	$68.96	$0.48	$28.16	$3.49	$1.40	$2.15	$0.00	$0.00
2352	Painting & wall covering contractors	$16.74	$0.00	$0.00	$2.54	$2.19	$0.25	$5.17	$2.29	$1.05	$3.25	$0.00	$0.00
2353	Electrical contractors	$58.31	$0.00	$0.00	$1.36	$38.67	$0.17	$16.90	$0.00	$0.00	$1.20	$0.00	$0.00
2354	Masonry, drywall, insulation, tile contractors	$1,858.30	$0.00	$0.00	$677.00	$23.39	$5.30	$83.11	$746.87	$275.96	$36.34	$10.32	$0.00
2355	Carpentry & floor contractors	$75.29	$0.00	$0.00	$14.48	$7.90	$14.58	$22.70	$4.03	$1.35	$10.25	$0.00	$0.00
2356	Roofing, siding, & sheet metal contractors	$14.60	$0.00	$0.00	$0.00	$1.57	$1.11	$11.93	$0.00	$0.00	$0.00	$0.00	$0.00
2357	Concrete contractors	$1,016.64	$0.00	$0.00	$362.35	$147.69	$2.04	$126.54	$28.15	$9.92	$339.95	$0.00	$0.00
2358	Water well drilling contractors	$240.29	$0.00	$232.14	$0.14	$6.31	$0.00	$1.58	$0.00	$0.00	$0.12	$0.00	$0.00
2359	Other special trade contractors	$1,274.56	$0.00	$172.55	$60.88	$814.38	$1.83	$141.05	$35.43	$14.21	$34.23	$0.00	$0.00
		$8,997.84	$0.00	$575.86	$1,543.54	$3,372.60	$71.84	$1,079.33	$965.78	$359.13	$801.73	$169.71	$58.32

Source: Calculated by mulitplying the total value of each at-risk task by the percentage of workers requiring controls. See Table 4-12.

Table 4-16

Compliance Costs ($millions): PEL = 75 Micrograms per Cubic Meter

			At-Risk Tasks										
NAICS	Title	All Tasks	Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	$0.18	$0.00	$0.00	$0.01	$0.08	$0.00	$0.09	$0.00	$0.00	$0.00	$0.00	$0.00
2332	Residential building construction	$14.84	$0.00	$0.00	$6.35	$0.86	$0.81	$5.24	$0.37	$0.29	$0.92	$0.00	$0.00
2333	Nonresidential building construction	$25.53	$0.00	$0.00	$12.15	$1.94	$0.55	$7.68	$0.96	$0.72	$1.52	$0.00	$0.00
2341	Highway, street, bridge & tunnel construction	$22.75	$0.00	$0.35	$3.42	$7.19	$0.03	$4.98	$0.03	$0.02	$2.01	$4.71	$0.01
2349	Other heavy construction	$24.72	$0.00	$3.41	$2.47	$10.04	$0.08	$7.67	$0.10	$0.08	$0.56	$0.32	$0.00
2351	Plumbing, heating & AC contractors	$2.13	$0.00	$0.00	$0.29	$0.61	$0.02	$1.13	$0.04	$0.03	$0.03	$0.00	$0.00
2352	Painting & wall covering contractors	$0.47	$0.00	$0.00	$0.15	$0.02	$0.01	$0.21	$0.02	$0.02	$0.04	$0.00	$0.00
2353	Electrical contractors	$1.12	$0.00	$0.00	$0.08	$0.34	$0.01	$0.68	$0.00	$0.00	$0.02	$0.00	$0.00
2354	Masonry, drywall, insulation, tile contractors	$56.89	$0.00	$0.00	$39.34	$0.21	$0.17	$3.32	$7.52	$5.52	$0.49	$0.33	$0.00
2355	Carpentry & floor contractors	$2.49	$0.00	$0.00	$0.84	$0.07	$0.47	$0.91	$0.04	$0.03	$0.14	$0.00	$0.00
2356	Roofing, siding, & sheet metal contractors	$0.53	$0.00	$0.00	$0.00	$0.01	$0.04	$0.48	$0.00	$0.00	$0.00	$0.00	$0.00
2357	Concrete contractors	$32.53	$0.00	$0.00	$21.05	$1.31	$0.07	$5.06	$0.28	$0.20	$4.56	$0.00	$0.00
2358	Water well drilling contractors	$5.23	$0.00	$5.10	$0.01	$0.06	$0.00	$0.06	$0.00	$0.00	$0.00	$0.00	$0.00
2359	Other special trade contractors	$21.37	$0.00	$3.79	$3.54	$7.24	$0.06	$5.64	$0.36	$0.28	$0.46	$0.00	$0.00
	Totals	$210.78	$0.00	$12.66	$89.68	$29.99	$2.31	$43.12	$9.72	$7.18	$10.75	$5.36	$0.01

Source: Calculated by multiplying the value of each at-risk task requiring controls by the percentage increase in project controls due to addtional dust controls. See Table 4-7.

Table 4-17

Total Value of At-Risk Tasks Requiring Controls ($millions): PEL = 100 Micrograms per Cubic Meter

			At-Risk Tasks										
NAICS	Title	All Tasks	Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	$8.13	$0.00	$0.00	$0.14	$5.80	$0.12	$2.00	$0.00	$0.00	$0.07	$0.00	$0.00
2332	Residential building construction	$381.39	$0.00	$0.00	$100.26	$64.65	$25.28	$114.47	$33.52	$8.88	$34.33	$0.00	$0.00
2333	Nonresidential building construction	$687.91	$0.00	$0.00	$191.84	$145.27	$17.22	$167.86	$86.82	$22.09	$56.82	$0.00	$0.00
2341	Highway, street, bridge & tunnel construction	$987.85	$0.00	$13.39	$53.92	$539.18	$0.93	$108.80	$2.94	$0.70	$75.12	$149.12	$43.74
2349	Other heavy construction	$1,133.12	$0.00	$129.25	$38.94	$752.79	$2.53	$167.65	$8.59	$2.31	$20.79	$10.27	$0.00
2351	Plumbing, heating & AC contractors	$80.69	$0.00	$0.00	$4.56	$45.97	$0.48	$24.59	$3.16	$0.86	$1.07	$0.00	$0.00
2352	Painting & wall covering contractors	$12.90	$0.00	$0.00	$2.33	$1.46	$0.25	$4.51	$2.08	$0.65	$1.62	$0.00	$0.00
2353	Electrical contractors	$42.56	$0.00	$0.00	$1.25	$25.78	$0.17	$14.76	$0.00	$0.00	$0.60	$0.00	$0.00
2354	Masonry, drywall, insulation, tile contractors	$1,589.65	$0.00	$0.00	$621.01	$15.60	$5.30	$72.58	$676.85	$169.82	$18.17	$10.32	$0.00
2355	Carpentry & floor contractors	$62.56	$0.00	$0.00	$13.28	$5.27	$14.58	$19.82	$3.66	$0.83	$5.12	$0.00	$0.00
2356	Roofing, siding, & sheet metal contractors	$12.57	$0.00	$0.00	$0.00	$1.04	$1.11	$10.42	$0.00	$0.00	$0.00	$0.00	$0.00
2357	Concrete contractors	$744.97	$0.00	$0.00	$332.38	$98.46	$2.04	$110.50	$25.51	$6.11	$169.97	$0.00	$0.00
2358	Water well drilling contractors	$199.23	$0.00	$193.45	$0.13	$4.21	$0.00	$1.38	$0.00	$0.00	$0.06	$0.00	$0.00
2359	Other special trade contractors	$925.53	$0.00	$143.79	$55.85	$542.92	$1.83	$123.17	$32.11	$8.75	$17.11	$0.00	$0.00
		$6,869.07	$0.00	$479.88	$1,415.88	$2,248.40	$71.84	$942.51	$875.24	$221.00	$400.86	$169.71	$43.74

Source: Calculated by mulitplying the total value of each at-risk task by the percentage of workers requiring controls. See Table 4-12.

Table 4-18

Compliance Costs ($millions): PEL = 100 Micrograms per Cubic Meter

NAICS	Title	All Tasks	At-Risk Tasks										
			Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
2331	Land subdivision & land development	$0.14	$0.00	$0.00	$0.01	$0.05	$0.00	$0.08	$0.00	$0.00	$0.00	$0.00	$0.00
2332	Residential building construction	$12.76	$0.00	$0.00	$5.83	$0.57	$0.81	$4.57	$0.34	$0.18	$0.46	$0.00	$0.00
2333	Nonresidential building construction	$21.78	$0.00	$0.00	$11.15	$1.29	$0.55	$6.71	$0.87	$0.44	$0.76	$0.00	$0.00
2341	Highway, street, bridge & tunnel construction	$18.36	$0.00	$0.29	$3.13	$4.79	$0.03	$4.35	$0.03	$0.01	$1.01	$4.71	$0.01
2349	Other heavy construction	$19.31	$0.00	$2.84	$2.26	$6.69	$0.08	$6.70	$0.09	$0.05	$0.28	$0.32	$0.00
2351	Plumbing, heating & AC contractors	$1.73	$0.00	$0.00	$0.26	$0.41	$0.02	$0.98	$0.03	$0.02	$0.01	$0.00	$0.00
2352	Painting & wall covering contractors	$0.39	$0.00	$0.00	$0.14	$0.01	$0.01	$0.18	$0.02	$0.01	$0.02	$0.00	$0.00
2353	Electrical contractors	$0.91	$0.00	$0.00	$0.07	$0.23	$0.01	$0.59	$0.00	$0.00	$0.01	$0.00	$0.00
2354	Masonry, drywall, insulation, tile contractors	$50.07	$0.00	$0.00	$36.08	$0.14	$0.17	$2.90	$6.82	$3.40	$0.24	$0.33	$0.00
2355	Carpentry & floor contractors	$2.20	$0.00	$0.00	$0.77	$0.05	$0.47	$0.79	$0.04	$0.02	$0.07	$0.00	$0.00
2356	Roofing, siding, & sheet metal contractors	$0.46	$0.00	$0.00	$0.00	$0.01	$0.04	$0.42	$0.00	$0.00	$0.00	$0.00	$0.00
2357	Concrete contractors	$27.33	$0.00	$0.00	$19.31	$0.88	$0.07	$4.42	$0.26	$0.12	$2.28	$0.00	$0.00
2358	Water well drilling contractors	$4.35	$0.00	$4.25	$0.01	$0.04	$0.00	$0.06	$0.00	$0.00	$0.00	$0.00	$0.00
2359	Other special trade contractors	$16.94	$0.00	$3.16	$3.24	$4.83	$0.06	$4.92	$0.32	$0.17	$0.23	$0.00	$0.00
	Totals	$176.74	$0.00	$10.55	$82.27	$19.99	$2.31	$37.66	$8.81	$4.42	$5.37	$5.36	$0.01

Source: Calculated by multiplying the value of each at-risk task requiring controls by the percentage increase in project controls due to addtional dust controls. See Table 4-7.

Land subdivision and development is associated with the lowest compliance cost of $235,924. The only workers employed in this industry who are exposed to silica dust are tractor and heavy equipment operators. ERG estimated that the full-time equivalent of only 861 workers are engaged in silica generating tasks.

Productivity impacts account for roughly 60 to 65 percent of total compliance costs across the three options. Tables 4-19, 4-20, and 4-21 present the productivity share calculations and demonstrate the, the importance of the productivity impacts. On an absolute basis, the productivity impacts are largest for grinders and tuckpointers ($75.9 million per year) and impact drillers ($36.0 million per year) for the PEL 50 $\mu g/m^3$ option.

4.8 PROGRAM COSTS FOR SILICA CONTROL

ERG estimated the costs of introducing prospective silica control programs to the construction industry. Based on the information provided by OSHA, ERG estimated program costs for exposure assessment, respirators, regulated areas, hygiene requirements, health screening and surveillance, and information and training programs.

ERG judged that employers will comply with these requirements by including workers who are either currently exposed or are at all likely to be exposed to silica hazards during their work. Thus, ERG assumed that employers will include program elements for employees who perform dusty tasks, even if only sporadically. This step is forecast to be less costly for employers than manipulating worker assignments so that only those with silica-related training and health screening are allowed to perform certain dusty tasks. Instead, employers will develop inclusive programs and retain the latitude to assign workers according to normal scheduling demands. The extent of program inclusion is described further below. ERG estimated the extent to which similar program elements are currently provided to workers. ERG used from the National Occupational Exposure Survey (NOES, 1988), which provides relevant survey estimates of employees covered by similar program elements.

Table 4-19

Productivity Impacts as a Percent of Total Compliance Costs ($millions): PEL = 50 Micrograms per Cubic Meter

Task Category	Total Compliance Costs	Compliance Costs Due to Productivity Impacts		Compliance Costs Excluding Productivity Impacts	
		Costs	Percent of Total	Costs	Percent of Total
Drywall finishers	$1.24	$0.97	78.5%	$0.27	21.5%
Earth drillers	$15.83	$0.00	0.0%	$15.83	100.0%
Grinders and tuck pointers using hand-held tools	$93.06	$75.86	81.5%	$17.19	18.5%
Heavy construction equipment operators	$39.99	$0.00	0.0%	$39.99	100.0%
Hole drillers using held-held drills	$11.54	$7.06	61.2%	$4.48	38.8%
Impact drillers	$47.98	$35.98	75.0%	$12.00	25.0%
Masonry cutters using portable saws	$10.64	$9.95	93.5%	$0.69	6.5%
Masonry cutters using stationary saws	$8.29	$8.29	100.0%	$0.00	0.0%
Millers using portable or mobile machines	$10.75	$6.60	61.4%	$4.15	38.6%
Rock crushing machines and tenders	$5.36	$0.00	0.0%	$5.36	100.0%
Underground construction (tunnel) work	$0.01	$0.00	0.0%	$0.01	100.0%
Totals	$244.67	$144.72	59.2%	$99.94	40.8%

Source: Share of compliance costs due to productivity impacts derived from Tables 4-6 and 4-7.

Table 4-20

Productivity Impacts as a Percent of Total Compliance Costs ($millions): PEL = 75 Micrograms per Cubic Meter

Task Category	Total Compliance Costs	Compliance Costs Due to Productivity Impacts		Compliance Costs Excluding Productivity Impacts	
		Costs	Percent of Total	Costs	Percent of Total
Drywall finishers	$0.00	$0.00	78.5%	$0.00	NA
Earth drillers	$12.66	$0.00	0.0%	$12.66	100.0%
Grinders and tuck pointers using hand-held tools	$89.68	$73.11	81.5%	$16.57	18.5%
Heavy construction equipment operators	$29.99	$0.00	0.0%	$29.99	100.0%
Hole drillers using held-held drills	$2.31	$1.41	61.2%	$0.90	38.8%
Impact drillers	$43.12	$32.34	75.0%	$10.79	25.0%
Masonry cutters using portable saws	$9.72	$9.10	93.5%	$0.63	6.5%
Masonry cutters using stationary saws	$7.18	$7.18	100.0%	$0.00	0.0%
Millers using portable or mobile machines	$10.75	$6.60	61.4%	$4.15	38.6%
Rock crushing machines and tenders	$5.36	$0.00	0.0%	$5.36	100.0%
Underground construction (tunnel) work	$0.01	$0.00	0.0%	$0.01	100.0%
Totals	$210.78	$129.74	61.6%	$81.04	38.4%

Source: Share of compliance costs due to productivity impacts derived from Tables 4-6 and 4-7.

Table 4-21

Productivity Impacts as a Percent of Total Compliance Costs ($millions): PEL = 100 Micrograms per Cubic Meter

Task Category	Total Compliance Costs	Compliance Costs Due to Productivity Impacts		Compliance Costs Excluding Productivity Impacts	
		Costs	Percent of Total	Costs	Percent of Total
Drywall finishers	$0.00	$0.00	78.5%	$0.00	NA
Earth drillers	$10.55	$0.00	0.0%	$10.55	100.0%
Grinders and tuck pointers using hand-held tools	$82.27	$67.07	81.5%	$15.20	18.5%
Heavy construction equipment operators	$19.99	$0.00	0.0%	$19.99	100.0%
Hole drillers using held-held drills	$2.31	$1.41	61.2%	$0.90	38.8%
Impact drillers	$37.66	$28.24	75.0%	$9.42	25.0%
Masonry cutters using portable saws	$8.81	$8.24	93.5%	$0.57	6.5%
Masonry cutters using stationary saws	$4.42	$4.42	100.0%	$0.00	0.0%
Millers using portable or mobile machines	$5.37	$3.30	61.4%	$2.07	38.6%
Rock crushing machines and tenders	$5.36	$0.00	0.0%	$5.36	100.0%
Underground construction (tunnel) work	$0.01	$0.00	0.0%	$0.01	100.0%
Totals	$176.74	$112.68	63.8%	$64.06	36.2%

Source: Share of compliance costs due to productivity impacts derived from Tables 4-6 and 4-7.

As shown in Table 4-22, ERG identified the number of at-risk full-time equivalent workers by industry and then increased those estimates to encompass the share of workers who are likely to be exposed to respirable silica periodically, whether they are dedicated to performing dusty operations or not. ERG classified the affected construction industries according to whether silica-generating tasks are distributed narrowly or widely among workers in the industry. For the industries where such activities are narrowly distributed among relatively specialized workers, ERG nevertheless estimated that the number of workers requiring participation in silica control programs would be twice the full-time equivalent number of workers estimated for the technical compliance cost calculations. (If the resulting estimate exceeded the total number of workers in the industry, it was limited to the industry total.) Thus, there is some breadth to the distribution of silica-generating tasks among workers in all industries. The construction industries include a sufficiently diverse mix of occupations that large numbers of workers are likely to perform silica-generating tasks with some regularity. Further, employers will likely wish to define participation in silica programs inclusively so as to avoid limitations on possible worker assignments based on worker readiness or lack thereof for performing silica-generating activities.

For industries where silica-generating work is widely distributed, ERG increased the number of workers to be included in programs by a factor of 5 over the full-time equivalent workers used in the technical compliance cost analysis. Thus, ERG judged that large shares of workers in certain occupations, such as brickmasons, sometimes will engage in dusty operations, such as grinding. Even though such dusty operations represent a small part of most jobs (and thus the full-time equivalent number of workers incurring technical compliance costs represent only a small share of the occupational or industry total number of workers), most workers will sometimes perform the dusty tasks. Similarly, a potentially large share of construction laborers in highway and street construction will sometimes perform impact drilling, even though such activities do not represent a large portion of all hours spent by construction laborers in this industry.

As shown, these adjustments result in an estimate of 1,399,722 at-risk workers. Overall, ERG forecasts that all at-risk workers in several industries will participate in silica programs. Given the occupations included in the analysis (see Table 4-9 above) and their frequent dustiness, widespread participation in the silica program elements appears necessary. Table 4-22 also shows the estimated

Table 4-22

Profile of Workers Exposed to Crystalline Silica

NAICS	Industry Title	Total Employment	Total Const. Workers in At-Risk Occupations [a]	FTE At-Risk Workers [a]	Wide or Narrow Distribution of Silica Exposures [b]	Adjusted Est. of Workers At-Risk	Exposure Profile - Workers Exposed in Excess of PEL Option or Action Level (micrograms per cubic meter)							
							40		50		75		100	
2331	Land subdivision & land development	77,885	4,969	861	Narrow	1,722	457	26.5%	394	22.9%	297	17.2%	222	12.9%
2332	Residential building construction	781,012	472,669	25,695	Narrow	51,389	26,964	52.5%	23,930	46.6%	16,999	33.1%	14,202	27.6%
2333	Nonresidential building construction	746,016	433,883	39,569	Wide	197,846	92,726	46.9%	83,512	42.2%	67,887	34.3%	55,841	28.2%
2341	Highway, street, bridge & tunnel construction	304,936	187,963	69,346	Wide	187,963 [c]	50,518	26.9%	44,649	23.8%	37,042	19.7%	27,636	14.7%
2349	Other heavy construction	596,051	285,449	99,561	Narrow	199,123	51,847	26.0%	45,038	22.6%	35,749	18.0%	26,569	13.3%
2351	Plumbing, heating & AC contractor	897,912	57,377	6,336	Narrow	12,671	3,834	30.3%	3,373	26.6%	2,728	21.5%	2,118	16.7%
2352	Painting & wall covering contractors	221,787	20,183	1,325	Narrow	2,650	861	32.5%	751	28.3%	554	20.9%	449	16.9%
2353	Electrical contractors	815,056	43,687	3,141	Narrow	6,281	1,869	29.7%	1,650	26.3%	1,338	21.3%	1,035	16.5%
2354	Masonry, drywall, insulation, tile contractors	564,994	381,992	90,312	Wide	381,992 [c]	184,529	48.3%	162,472	42.5%	140,426	36.8%	120,106	31.4%
2355	Carpentry & floor contractors	347,303	198,136	6,252	Narrow	12,504	7,225	57.8%	6,099	48.8%	2,925	23.4%	2,554	20.4%
2356	Roofing, siding, & sheet metal contractors	260,774	34,161	818	Narrow	1,635	1,055	64.5%	935	57.2%	627	38.3%	549	33.6%
2357	Concrete contractors	292,569	216,062	36,218	Wide	181,092	91,885	50.7%	87,451	48.3%	80,998	44.7%	64,559	35.6%
2358	Water well drilling contractors	21,590	11,108	8,179	Narrow	11,108 [c]	6,376	57.4%	5,688	51.2%	4,552	41.0%	3,744	33.7%
2359	Other special trade contractors	644,915	218,368	75,872	Narrow	151,745	42,197	27.8%	36,788	24.2%	29,525	19.5%	22,289	14.7%
	Total	6,572,800	2,566,007	463,486		1,399,722	562,342	40.2%	502,730	35.9%	421,647	30.1%	341,873	24.4%

Sources and notes:

[a] The population of at-risk workers, when presented by industry, differs slightly from the at-risk total presented by occupation because a small number of secondary workers are employed in industries where there are no key workers. These *workers are not included in the by-industry totals. See Tables 4-9 and 4-10.*

[b] Estimated by ERG based on the likelihood that silica exposures are widely distributed among workers, i.e., that many workers spend at least some time on dusty operations.

[c] Includes all workers in at-risk occupations.

percentages of the at-risk employees exposed at levels greater than the PEL or action levels considered by the draft standard.

4.8.1 Exposure Assessment

Based on discussions with OSHA and draft regulatory language, ERG used the following assumptions in generating exposure assessment costs:

(1) Employers will perform initial assessments of their workers performing dusty tasks (as delineated in Table 1 of the draft standard);
(2) For workers found to be exposed below the action level, no further action is necessary.
(3) Workers found to be over the PEL must comply with Table 1. Because they are then using respirators, where appropriate, per Table 1 requirements, there are no further monitoring requirements.
(4) Periodic monitoring is required for workers exposed above the action level, but below the PEL.

Table 4-23 shows the unit costs and assumptions for the exposure assessment requirement. Most establishments wishing to perform exposure monitoring will require the assistance of an outside consulting industrial hygienist (IH) to obtain accurate results. While some firms might already employ or train qualified staff, ERG judged that the testing protocols are fairly challenging and few firms have competent staff to obviate the need for outside consultants.

The OSH Act provides for the right of an employee-designated representative to observe exposure monitoring and measuring procedures. ERG has not identified any data on how frequently this right is exercised. In some cases, union officials might observe monitoring no direct cost to the employer. For these reasons, ERG added no additional cost for this provision.

The draft standard does not require that each worker be monitored, and ERG estimated that the exposure assessment requirement would be satisfied through testing, on average, of one worker in every

Table 4-23

Exposure Assessment
Assumptions and Unit Costs
Coverage: All employees exposed above action level and below the PEL

	Cost	Comments/Assumptions
Direct Costs		
IH fees/sample	$75.00	Consulting IH technician - hourly rate (one sample per hour)
Lab Fees and shipping cost	$105.50	Lab fees (EMSL Laboratory, 2000) and OSHA estimates
Total - PBZ sample	$180.50	
IH fees/direct read	$37.50	Consulting IH technician- hourly rate (two readings per hour)
Direct read instrument per day	$80.00	ASC Master-Tek Rentals, daily rate. http://www.ascrents.com/pages/asc_aerosol.htm
Total - Direct read sample	$77.50	Assumes two readings in a day.
Requirements		
Number of workers per sample	4	Estimated by ERG based on forecast of need for monitoring
Freqency of periodic sampling (per year)		
PEL=50	4	Based on requirements in the draft standard
PEL=75 or 100	2	Based on requirements in the draft standard
Time Requirements		
Worker productivity loss while pump is attached to employee.	30 mins	Estimated to include time for set-up and productivity loss
Recordkeeping by a manager	10 mins	Includes time to notify employees of results
Unit Costs		
Cost per sample (PBZ)	$198.18	Includes IH time, lab fees, worker and management labor costs
Cost per sample (Direct read)	$95.18	Includes IH time, instrument time, worker and management labor costs
Cost per year	PBZ Samples	Direct Read
PEL=100; 75	$396.35	$190.35
PEL=50	$792.71	$380.71

four. This level was judged sufficient to characterize exposures among at-risk workers across the range of activities likely to be undertaken. Personal breathing zone (PBZ) samples are required for initial monitoring and for periodic monitoring under option 1 of the draft standard. ERG assumed that an IH will be able to obtain samples while spending 1 hour per worker sampled. Based on the 2000 EMSL Laboratory Testing Catalog, ERG estimated that each sample will cost $105.50 for analysis. When combined with the IH hourly fee, the cost per sample is projected at $180.50. Other costs stem from the loss of the employee's productive time while the pump is attached and the time needed to record sampling results. Overall, ERG estimated unit costs for personal breathing zone samples at $198.18 per sample.

Option 1 in the draft standard requires semi-annual periodic sampling for the 75 and 100 $\mu g/m^3$ PEL options and quarterly sampling for the 50 $\mu g/m^3$ PEL option. Option 2 for periodic monitoring requires sampling "as necessary," and permits employers to use assessment methods such as direct-read instruments to supplement personal air quality monitoring. For option 2, ERG used unit costs of $95.18 per sample taken with direct-read instruments and assumed the same sampling frequency as required under option 1. Samples taken with direct-read instruments are less expensive and require less IH time per sample. See Table 4-23 for the derivation and basis for this unit cost estimate.

Tables 4-24, 4-25, and 4-26 show the annualized total exposure assessment costs, by industry, for each of the PEL options. These costs combine the initial assessments, annualized over ten years, and the annual costs for periodic monitoring. For option 1, these costs range from $23.8 million (75 $\mu g/m^3$ PEL) to $9.8 million (50 $\mu g/m^3$ PEL). For option 2, these costs range from $17.5 million (100 $\mu g/m^3$ PEL) and $9.8 million (50 $\mu g/m^3$ PEL). For the 50 $\mu g/m^3$ PEL option, no periodic monitoring is mandated since the action level and PEL are identical.

4.8.2 Respirator Costs

The proposed standard will require employers to perform initial monitoring of workers performing dusty tasks. Those workers found to be receiving exposures above the PEL will be required to use the engineering controls and respirators (where required), as prescribed Table 1 in the standard. This

Table 4-24

Exposure Monitoring: PEL Option=50; Action Level=50
Annualized Costs, Construction Industry

			Option: PEL =50				
				Periodic Assessment [b]		Total	
NAICS	Industry Title	Adjusted At-Risk Workers	Initial Assess-ment [a]	Option 1	Option 2	Option 1	Option 2
2331	Land subdivision & land development	1,722	$12,149	$0	$0	$12,149	$12,149
2332	Residential building construction	51,389	$362,498	$0	$0	$362,498	$362,498
2333	Nonresidential building construction	197,846	$1,395,607	$0	$0	$1,395,607	$1,395,607
2341	Highway, street, bridge & tunnel construction	187,963	$1,325,891	$0	$0	$1,325,891	$1,325,891
2349	Other heavy construction	199,123	$1,404,611	$0	$0	$1,404,611	$1,404,611
2351	Plumbing, heating & AC contractor	12,671	$89,384	$0	$0	$89,384	$89,384
2352	Painting & wall covering contractors	2,650	$18,696	$0	$0	$18,696	$18,696
2353	Electrical contractors	6,281	$44,310	$0	$0	$44,310	$44,310
2354	Masonry, drywall, insulation, tile contractors	381,992	$2,694,572	$0	$0	$2,694,572	$2,694,572
2355	Carpentry & floor contractors	12,504	$88,203	$0	$0	$88,203	$88,203
2356	Roofing, siding, & sheet metal contractors	1,635	$11,536	$0	$0	$11,536	$11,536
2357	Concrete contractors	181,092	$1,277,420	$0	$0	$1,277,420	$1,277,420
2358	Water well drilling contractors	11,108	$78,356	$0	$0	$78,356	$78,356
2359	Other special trade contractors	151,745	$1,070,408	$0	$0	$1,070,408	$1,070,408
	Total	1,399,722	$9,873,641	$0	$0	$9,873,641	$9,873,641

[a] Assumes intial assessment for all adjusted FTE workers at risk. See Table 4-14. Initial monitoring costs annualized over ten years.
[b] Assumes periodic assessments for workers exposed between the action level and the PEL. No workers are in this category for the PEL=50.
Note: Workers otherwise exposed above the PEL are assumed to comply with Table 1.

Table 4-25

Exposure Monitoring: PEL Option =75; Action Level=40
Annualized Costs, Construction Industry

			Option: PEL =75				
		Adjusted At-Risk Workers	Initial Assess-ment [a]	Periodic Assessment [b]		Total	
NAICS	Industry Title			Option 1	Option 2	Option 1	Option 2
2331	Land subdivision & land development	1,722	$12,149	$15,868	$7,621	$28,017	$19,770
2332	Residential building construction	51,389	$362,498	$987,444	$474,233	$1,349,942	$836,732
2333	Nonresidential building construction	197,846	$1,395,607	$2,461,268	$1,182,058	$3,856,874	$2,577,664
2341	Highway, street, bridge & tunnel construction	187,963	$1,325,891	$1,335,339	$641,315	$2,661,231	$1,967,207
2349	Other heavy construction	199,123	$1,404,611	$1,595,132	$766,084	$2,999,743	$2,170,695
2351	Plumbing, heating & AC contractor	12,671	$89,384	$109,601	$52,637	$198,984	$142,021
2352	Painting & wall covering contractors	2,650	$18,696	$30,396	$14,598	$49,092	$33,294
2353	Electrical contractors	6,281	$44,310	$52,558	$25,242	$96,868	$69,551
2354	Masonry, drywall, insulation, tile contractors	381,992	$2,694,572	$4,370,103	$2,098,802	$7,064,676	$4,793,375
2355	Carpentry & floor contractors	12,504	$88,203	$426,016	$204,600	$514,219	$292,803
2356	Roofing, siding, & sheet metal contractors	1,635	$11,536	$42,438	$20,382	$53,974	$31,917
2357	Concrete contractors	181,092	$1,277,420	$1,078,798	$518,108	$2,356,219	$1,795,528
2358	Water well drilling contractors	11,108	$78,356	$180,729	$86,798	$259,085	$165,153
2359	Other special trade contractors	151,745	$1,070,408	$1,255,653	$603,045	$2,326,061	$1,673,453
	Total	1,399,722	$9,873,641	$13,941,344	$6,695,522	$23,814,985	$16,569,163

[a] Assumes intial assessment for all adjusted FTE workers at risk. See Table 4-14. Initial monitoring costs annualized over ten years.
[b] Assumes periodic assessment for workers between the action level and the PEL.
Note: Workers exposed above the PEL are assumed to comply with Table 1.

Table 4-26

Exposure Monitoring: PEL Option=100; Action Level=50
Annualized Costs, Construction Industry

			Option: PEL =100				
		Adjusted At-Risk Workers	Initial Assess-ment [a]	Periodic Screening [b]		Total	
NAICS	Industry Title			Option 1	Option 2	Option 1	Option 2
2331	Land subdivision & land development	1,722	$12,149	$17,077	$8,201	$29,226	$20,351
2332	Residential building construction	51,389	$362,498	$963,871	$462,912	$1,326,370	$825,411
2333	Nonresidential building construction	197,846	$1,395,607	$2,741,875	$1,316,823	$4,137,481	$2,712,430
2341	Highway, street, bridge & tunnel construction	187,963	$1,325,891	$1,685,844	$809,650	$3,011,735	$2,135,541
2349	Other heavy construction	199,123	$1,404,611	$1,830,147	$878,953	$3,234,758	$2,283,564
2351	Plumbing, heating & AC contractor	12,671	$89,384	$124,438	$59,763	$213,822	$149,147
2352	Painting & wall covering contractors	2,650	$18,696	$29,945	$14,382	$48,641	$33,078
2353	Electrical contractors	6,281	$44,310	$60,969	$29,281	$105,279	$73,591
2354	Masonry, drywall, insulation, tile contractors	381,992	$2,694,572	$4,197,996	$2,016,145	$6,892,568	$4,710,718
2355	Carpentry & floor contractors	12,504	$88,203	$351,216	$168,676	$439,419	$256,879
2356	Roofing, siding, & sheet metal contractors	1,635	$11,536	$38,217	$18,354	$49,752	$29,890
2357	Concrete contractors	181,092	$1,277,420	$2,268,348	$1,089,405	$3,545,768	$2,366,826
2358	Water well drilling contractors	11,108	$78,356	$192,638	$92,517	$270,994	$170,873
2359	Other special trade contractors	151,745	$1,070,408	$1,436,612	$689,953	$2,507,020	$1,760,361
	Total	1,399,722	$9,873,641	$15,939,193	$7,655,017	$25,812,833	$17,528,657

[a] Assumes intial assessment for all adjusted FTE workers at risk. See Table 4-14. Initial monitoring costs annualized over ten years.
[b] Assumes periodic assessment for workers between the action level and the PEL.
Note: Workers exposed above the PEL are assumed to comply with Table 1.

requirement will lead to a substantial increase in the use of respirators in construction. The specific respirator requirement depends on the engineering control method used and the PEL option.

Using Table 1 in the standard, ERG first identified the respirators for each of the tasks evaluated in the engineering cost analysis. Where respirators varied among control methods for a given task, ERG used the respirator type associated with the most commonly used control method. The respirator specifications are shown in Table 4-27. The table (see bottom of the table) also shows for each respirator type, annual unit costs as derived in an earlier respirator study for OSHA (ERG, 2003). These unit costs reflect the annualized cost of respirator use, including accessories (e.g., filters), training, fit testing, and cleaning.

Table 4-28 shows the aggregate respirator costs for the adjusted full-time equivalent at-risk workers by task, industry, and PEL option. The annualized cost per worker to use a half-mask nonpowered air-purifying respirator is estimated at $469 per year, and for a full-face nonpowered air-purifying respirator at $547 per year. These costs are inclusive of all related accessory, training, fit testing, and cleaning costs. The annual costs of respirator use are estimated at $175 million per year for the 50 $\mu g/m^3$ option, and declining to $163 million and $120 million per year for the 75 and 100 $\mu g/m^3$ options. These costs are most highly concentrated for the grinding and tuckpointing activity where many workers are believed to be exposed over at high levels and where Table 1 specifies that tuckpointers must wear full-face respirators. Table 1 does not specify respirators for some workers, such as drywall finishers, heavy equipment operators, hole drillers, tunnel workers, and, depending upon the PEL, some other categories of workers. In these cases, Table 4-28 shows zero costs.

These costs overestimate respirator compliance costs to the extent construction workers are currently using the respirators specified in Table 1 of the standard. (ERG industrial hygienists, however, have observed low levels of respirator use among affected workers, so this bias may be small.)

4.8.3 Regulated Areas

The draft standard requires employers to establish regulated areas whenever workers' exposures can be reasonably expected to exceed the PEL. Specifically, the standard requires employers to establish a

Table 4-27

Respirator Specifications for Cost Analysis

Task	Respirator Selection - PEL Option 50	Respirator Selection - PEL Option 75	Respirator Selection - PEL Option 100
Respirator Selection			
Drywall finishers	None	None	None
Earth drillers	Half-mask	Half-mask	Half-mask
Grinders and tuckpointers using hand-held tools [a]			
Grinders	Half-mask	Half-mask	Half-mask
Tuckpointers	Full-face	Full-face	Full-face
Operators of tractors and other heavy construction vehicles and equipment	None	None	None
Hole drillers using hand-held drills	None	None	None
Impact drillers	Half-mask	Half-mask	Half-mask
Masonry cutters using portable saws	Half-mask	Half-mask	Half-mask
Masonry cutting using stationary saws	Half-mask	Half-mask	None
Millers using portable or mobile machines	Half-mask	Half-mask	None
Rock-crushing machine operators and tenders	Full-face	Full-face	Half-mask
Underground construction workers	None	None	None
Respirator Cost			
Annualized cost ,including accessories, training, fit testing, and cleaning [b]	Half-mask nonpowered air-purifying respirator	$468.74	
	Full-face nonpowered air-purifying respirator	$546.87	

Source: Table 1, draft silica construction standard.
Note: Where differerent respirators are specified for various control methods, ERG selected the respirator required for the most common method.
[a] The cost analysis assumes that workers using grinders comprise 75 percent of the total for this task and that tuckpointers comprise 25 percent.
[b] See ERG, Support for a Revised Economic Analysis of a Proposed OSHA Standard for Assigned Protection Factors for Respirators: Final Report. May 16, 2003. Prepared for OSHA, Office of Regulatory Analysis.

Table 4-28

Respirator Costs by Industry, Task, and PEL Option

NAICS	Title	All Tasks	Drywall Finishing	Earth Drilling	Grinding and Tuckpointing	Heavy Equip. Operator	Hole Drilling	Impact Drilling	Portable Masonry Saws	Stationary Masonry Saws	Milling	Rock Crushing	Underground Work
PEL Option=50													
2331	Land subdivision & land development	$57,014	$0	$0	$3,546	$0	$0	$52,174	$0	$0	$1,295	$0	$0
2332	Residential building construction	$7,149,605	$0	$0	$2,622,403	$0	$0	$2,912,657	$574,863	$325,560	$714,123	$0	$0
2333	Nonresidential building construction	$28,899,495	$0	$0	$11,080,963	$0	$0	$9,802,153	$3,489,787	$1,976,359	$2,550,213	$0	$0
2341	Highway, street, bridge & tunnel construction	$9,242,761	$0	$290,569	$1,632,209	$0	$0	$3,300,009	$62,302	$35,283	$1,789,727	$2,132,661	$0
2349	Other heavy construction	$8,041,039	$0	$2,263,083	$936,229	$0	$0	$4,131,886	$132,145	$74,837	$388,934	$113,924	$0
2351	Plumbing, heating & AC contractors	$770,255	$0	$0	$102,201	$0	$0	$574,562	$47,776	$27,057	$18,659	$0	$0
2352	Painting & wall covering contractors	$254,733	$0	$0	$55,536	$0	$0	$121,961	$27,535	$15,594	$34,106	$0	$0
2353	Electrical contractors	$366,674	$0	$0	$27,831	$0	$0	$328,681	$0	$0	$10,163	$0	$0
2354	Masonry, drywall, insulation, tile contractors	$71,654,354	$0	$0	$30,396,122	$0	$0	$3,591,941	$23,470,539	$13,291,989	$675,386	$228,377	$0
2355	Carpentry & floor contractors	$1,044,599	$0	$0	$320,194	$0	$0	$522,019	$73,918	$41,862	$86,607	$0	$0
2356	Roofing, siding, & sheet metal contractors	$282,455	$0	$0	$0	$0	$0	$282,455	$0	$0	$0	$0	$0
2357	Concrete contractors	$37,207,811	$0	$0	$20,529,626	$0	$0	$6,818,085	$1,148,074	$650,185	$8,061,841	$0	$0
2358	Water well drilling contractors	$2,461,568	$0	$2,434,942	$2,356	$0	$0	$23,409	$0	$0	$860	$0	$0
2359	Other special trade contractors	$7,792,564	$0	$2,448,609	$1,299,258	$0	$0	$2,987,576	$474,689	$268,829	$313,603	$0	$0
	Total	$175,224,928	$0	$7,437,204	$69,008,494	$0	$0	$35,449,568	$29,501,629	$16,707,555	$14,645,517	$2,474,961	$0
PEL Option=75													
2331	Land subdivision & land development	$51,603	$0	$0	$3,417	$0	$0	$46,890	$0	$0	$1,295	$0	$0
2332	Residential building construction	$6,666,956	$0	$0	$2,527,388	$0	$0	$2,617,705	$525,589	$282,152	$714,123	$0	$0
2333	Nonresidential building construction	$26,942,748	$0	$0	$10,679,498	$0	$0	$8,809,530	$3,190,663	$1,712,845	$2,550,213	$0	$0
2341	Highway, street, bridge & tunnel construction	$8,781,286	$0	$232,456	$1,573,071	$0	$0	$2,965,831	$56,962	$30,579	$1,789,727	$2,132,661	$0
2349	Other heavy construction	$7,114,777	$0	$1,810,466	$902,308	$0	$0	$3,713,468	$120,819	$64,858	$388,934	$113,924	$0
2351	Plumbing, heating & AC contractors	$700,666	$0	$0	$98,498	$0	$0	$516,378	$43,681	$23,449	$18,659	$0	$0
2352	Painting & wall covering contractors	$235,931	$0	$0	$53,524	$0	$0	$109,611	$25,175	$13,515	$34,106	$0	$0
2353	Electrical contractors	$332,382	$0	$0	$26,823	$0	$0	$295,397	$0	$0	$10,163	$0	$0
2354	Masonry, drywall, insulation, tile contractors	$66,405,279	$0	$0	$29,294,813	$0	$0	$3,228,200	$21,458,779	$11,519,724	$675,386	$228,377	$0
2355	Carpentry & floor contractors	$968,218	$0	$0	$308,593	$0	$0	$469,157	$67,582	$36,280	$86,607	$0	$0
2356	Roofing, siding, & sheet metal contractors	$253,852	$0	$0	$0	$0	$0	$253,852	$0	$0	$0	$0	$0
2357	Concrete contractors	$35,588,447	$0	$0	$19,785,799	$0	$0	$6,127,646	$1,049,668	$563,494	$8,061,841	$0	$0
2358	Water well drilling contractors	$1,972,124	$0	$1,947,954	$2,271	$0	$0	$21,039	$0	$0	$860	$0	$0
2359	Other special trade contractors	$6,876,697	$0	$1,958,888	$1,252,183	$0	$0	$2,685,036	$434,001	$232,985	$313,603	$0	$0
	Total	$162,890,965	$0	$5,949,763	$66,508,186	$0	$0	$31,859,738	$26,972,918	$14,479,881	$14,645,517	$2,474,961	$0
PEL Option=100													
2331	Land subdivision & land development	$44,081	$0	$0	$3,135	$0	$0	$40,946	$0	$0	$0	$0	$0
2332	Residential building construction	$5,080,554	$0	$0	$2,318,356	$0	$0	$2,285,883	$476,315	$0	$0	$0	$0
2333	Nonresidential building construction	$20,380,598	$0	$0	$9,796,232	$0	$0	$7,692,829	$2,891,538	$0	$0	$0	$0
2341	Highway, street, bridge & tunnel construction	$6,106,155	$0	$193,713	$1,442,968	$0	$0	$2,589,881	$51,622	$0	$0	$1,827,973	$0
2349	Other heavy construction	$5,786,289	$0	$1,508,722	$827,681	$0	$0	$3,242,746	$109,492	$0	$0	$97,648	$0
2351	Plumbing, heating & AC contractors	$580,859	$0	$0	$90,351	$0	$0	$450,922	$39,586	$0	$0	$0	$0
2352	Painting & wall covering contractors	$167,629	$0	$0	$49,097	$0	$0	$95,716	$22,815	$0	$0	$0	$0
2353	Electrical contractors	$282,556	$0	$0	$24,604	$0	$0	$257,952	$0	$0	$0	$0	$0
2354	Masonry, drywall, insulation, tile contractors	$49,333,693	$0	$0	$26,871,934	$0	$0	$2,818,991	$19,447,018	$0	$0	$195,749	$0
2355	Carpentry & floor contractors	$754,002	$0	$0	$283,070	$0	$0	$409,686	$61,246	$0	$0	$0	$0
2356	Roofing, siding, & sheet metal contractors	$221,674	$0	$0	$0	$0	$0	$221,674	$0	$0	$0	$0	$0
2357	Concrete contractors	$24,451,543	$0	$0	$18,149,379	$0	$0	$5,350,902	$951,261	$0	$0	$0	$0
2358	Water well drilling contractors	$1,643,750	$0	$1,623,295	$2,083	$0	$0	$18,372	$0	$0	$0	$0	$0
2359	Other special trade contractors	$5,519,019	$0	$1,632,406	$1,148,619	$0	$0	$2,344,680	$393,314	$0	$0	$0	$0
	Total	$120,352,401	$0	$4,958,136	$61,007,509	$0	$0	$27,821,180	$24,444,207	$0	$0	$2,121,370	$0

Note: Based on the adjusted full-time equivalent number of at-risk workers for each task exposed above the PEL.

regulated area around any of the operations listed in the draft standard's Table 1 where respiratory protection is required. Based on the respirators specifications shown in Table 4-27, ERG derived the full-time equivalent number of worker engaged in Table 1 tasks where respirators are required and estimated the costs of establishing regulated areas for these workers. These workers were found to be overexposed during initial monitoring and are therefore following the dictates of Table 1.

Table 4-29 shows the unit costs and assumptions for developing costs for regulated areas. The time allowed to set up a regulated area is intended to allow for the communication of access restrictions and locations at multi-employer worksites. ERG estimated a cost of $15.92 per job based on an estimated 20 minutes per job to set up the regulated area and the costs for hazard tape and warning signs (which are reusable). ERG aggregated costs by assuming an average crew size of four and an average job length of five days. Applying these parameters to the full-time-equivalent number of workers requiring respirators (as specified in Table 1), ERG calculated annual costs of $20.2 million for the 50 $\mu g/m^3$ PEL option, $18.6 million for the 75 $\mu g/m^3$ option, and $13.9 million for the 100 $\mu g/m^3$ PEL option (see Table 4-30).

4.8.4 Hygiene Requirements

The draft standard offers employers the option of providing disposable clothes for workers exposed above the PEL or, alternatively, providing a means for workers to vacuum excess dust from their clothing. ERG addressed only the second of these options because the latter will be substantially less expensive in virtually all circumstances and therefore is very likely to be selected by employers.[5]

ERG applied the unit compliance costs for this requirement to the full-time-equivalent at-risk workers (unadjusted) who are forecast to be exposed over the PEL. The elements of this calculation are presented in Table 4-22). Table 4-31 shows the annual cost of these hygiene requirements at $33.1 million for the 50 $\mu g/m^3$ PEL option, $27.2 million for the 75 $\mu g/m^3$ option, and $21.8 million for the 100 $\mu g/m^3$ PEL option.

[5] ERG calculated that the provision of disposable protective clothes (estimated to cost $3.86 per day) would cost $147.4 million per year for the 50 $\mu g/m^3$, while the provision of a HEPA vacuum and allowing two minutes per worker per day for cleaning clothes and shoes would cost $33.1 million per year.

Table 4-29

Cost Assumptions for Regulated Areas

Average crew size	4	Estimated by ERG
Average job length (days)	5	Estimated by ERG
Time to set up regulated area (mins)	20	Includes time to communicate access restrictions and locations at multi-employer worksites
Materials		
Hazard tape (100 ft.)	$4.80	$24 per 500 ft. roll (Lab Safety Supply, 1999)
Warning signs (3)	$42.45	@ $14.15 (Lab Safety Supply, 1999)
Warning signs - Annualized cost	$16.18	Assumes 3 year life
Materials cost per job	$5.12	Based on average job length; Includes tape and warning sign cost (latter is distributed over 50 jobs per year)
Labor time	$10.80	Valued at supervisor wage, adjusted for benefits
Total cost	$15.92	Sum of materials and labor/job

Table 4-30

Annual Costs for Regulated Areas
(Applied to FTE At-Risk Workers Exposed Above the PEL)

		PEL Option = 50			PEL Option = 75			PEL Option = 100		
NAICS	Industry Title	FTE At-Risk Workers [a]	No. of Jobs	Annual Cost	FTE At-Risk Workers [a]	No. of Jobs	Annual Cost	FTE At-Risk Workers [a]	No. of Jobs	Annual Cost
2331	Land subdivision & land development	61	758	$12,076	55	686	$10,928	47	586	$9,333
2332	Residential building construction	7,515	93,931	$1,495,809	7,004	87,547	$1,394,135	5,320	66,506	$1,059,068
2333	Nonresidential building construction	12,142	151,770	$2,416,857	11,314	141,419	$2,252,029	8,529	106,609	$1,697,691
2341	Highway, street, bridge & tunnel construction	6,984	87,295	$1,390,130	6,622	82,778	$1,318,200	4,761	59,508	$947,629
2349	Other heavy construction	8,520	106,500	$1,695,955	7,533	94,167	$1,499,569	6,137	76,711	$1,221,579
2351	Plumbing, heating & AC contractor	817	10,216	$162,681	743	9,290	$147,937	616	7,697	$122,567
2352	Painting & wall covering contractors	269	3,367	$53,616	249	3,117	$49,641	177	2,209	$35,176
2353	Electrical contractors	390	4,874	$77,620	353	4,418	$70,347	300	3,754	$59,787
2354	Masonry, drywall, insulation, tile contractors	35,512	443,894	$7,068,787	32,886	411,077	$6,546,199	24,341	304,261	$4,845,208
2355	Carpentry & floor contractors	1,101	13,758	$219,081	1,020	12,745	$202,962	792	9,903	$157,694
2356	Roofing, siding, & sheet metal contractors	301	3,766	$59,974	271	3,385	$53,901	236	2,956	$47,068
2357	Concrete contractors	15,525	194,066	$3,090,400	14,847	185,588	$2,955,391	10,123	126,539	$2,015,066
2358	Water well drilling contractors	4,108	51,348	$817,694	3,291	41,138	$655,103	2,743	34,288	$546,021
2359	Other special trade contractors	8,257	103,210	$1,643,568	7,282	91,023	$1,449,501	5,838	72,976	$1,162,103
	Totals	101,500	1,268,753	$20,204,248	93,470	1,168,379	$18,605,842	69,960	874,501	$13,925,989

[a] Estimated full-time equivalent workers exposed above the PEL in tasks where respirator use is required by Table 1 of the draft standard.

Table 4-31
Hygiene Requirements
Annualized Costs, Construction Industry
(Applied to FTE At-Risk Workers Exposed Above the PEL)

NAICS	Industry Title	PEL Option = 50		PEL Option = 75		PEL Option = 100	
		FTE At-Risk Workers [a]	Annualized Cost [b]	FTE At-Risk Workers [a]	Annualized Cost [b]	FTE At-Risk Workers [a]	Annualized Cost [b]
2331	Land subdivision & land development	197	$42,774	149	$32,210	111	$24,086
2332	Residential building construction	11,965	$2,594,808	8,500	$1,843,299	7,101	$1,540,020
2333	Nonresidential building construction	16,702	$3,622,238	13,577	$2,944,519	11,168	$2,422,038
2341	Highway, street, bridge & tunnel construction	16,473	$3,572,452	13,666	$2,963,763	10,196	$2,211,178
2349	Other heavy construction	22,519	$4,883,756	17,875	$3,876,474	13,284	$2,880,981
2351	Plumbing, heating & AC contractor	1,687	$365,796	1,364	$295,811	1,059	$229,620
2352	Painting & wall covering contractors	376	$81,450	277	$60,110	224	$48,680
2353	Electrical contractors	825	$178,957	669	$145,099	518	$112,237
2354	Masonry, drywall, insulation, tile contractors	38,412	$8,330,521	33,200	$7,200,133	28,396	$6,158,264
2355	Carpentry & floor contractors	3,049	$661,321	1,463	$317,204	1,277	$276,976
2356	Roofing, siding, & sheet metal contractors	467	$101,347	313	$67,987	274	$59,525
2357	Concrete contractors	17,490	$3,793,098	16,200	$3,513,215	12,912	$2,800,174
2358	Water well drilling contractors	4,189	$908,370	3,352	$726,856	2,757	$597,917
2359	Other special trade contractors	18,394	$3,989,072	14,762	$3,201,536	11,145	$2,416,952
	Total	152,745	$33,125,959	125,366	$27,188,216	100,422	$21,778,647

[a] Estimated full-time equivalent workers exposed above the PEL.
[b] Includes annualized cost of HEPA vacuum ($497) for each crew of four and the value of two minutes per day day for cleaning clothes and shoes.

The draft standard also requires employees to vacuum or otherwise clean their shoes even if they are provided with disposable clothing. ERG assigned no additional costs to this requirement because the cost analysis suggests, as noted above, that the HEPA vacuum option is substantially less expensive than providing disposable clothes and would be chosen by most employers. Also, shoe cleaning does not require a HEPA vacuum and could be accomplished at minimal cost through other methods (e.g., damp rags).

4.8.5 Health Screening

The draft standard requires an initial screening, periodic screenings in specified circumstances, as specified in two options, and exit screenings. For the periodic screenings, x-rays are required every three years (option 1) or on a frequency based on the worker's cumulative silica exposure (option 2). The specifications for the initial screening and for the periodic screenings under the two options are shown in Table 4-32. At OSHA's request, ERG also examined the implications for these provisions of the high turnover and job switching rates in construction.

ERG assembled information on the representative costs of initial and periodic health screenings. Costs were derived for each of two options regarding the extent and frequency of periodic screenings. Table 4-32 shows the unit costs for the required medical procedures and the time requirements for each. Health screening costs are assumed to apply to all at-risk workers (as adjusted) exposed above the action level who work on tasks corresponding to the activities listed in Table 1. Based on a ten-year time horizon, ERG calculated the annualized costs for both annual and periodic screenings. For option 2, ERG used workforce age data to approximate the distribution of workers by cumulative exposure.

ERG again used information from the 1988 NOES survey to estimate current compliance rates. According to NOES, the percentage of workers receiving x-rays ranges from less than 5 percent to as high as 14 percent, depending on the industry. ERG used these rates as a proxy for compliance for the silica health screening requirements.

Table 4-32

Health Screening and Surveillance
Per Employee Unit Costs

		Initial Screening	Periodic Screening		
Screening Tool	Unit Cost	Procedural Cost	Option 1	Option 2	Comments/Assumptions
Direct Costs					
1 Physical examination by knowlegeable health care professional	$103.33	Yes	Yes	Yes	Evaluation and office consultation including detailed examination.
2 Examination by pulmonary specialist	$253.76	NA	NA	NA	Office consultation and evaluation by a pulmonary specialist
3 Complete occupational and health history survey	$34.44	Yes	NA	NA	Assumed one third of physical exam cost
4 Review and/or updating of health history	$34.44	NA	Yes	Yes	Assumed one third of physical exam cost
5 Chest x-ray (ant/post 14 x 17)	$62.97	Yes	Yes; every 3 years	Yes; based on cumulative exposure	Radiologic examination, chest; stereo, frontal. Costs include consultation and written report.
6 Chest X-ray classified by a NIOSH-certified B Reader	$31.00	Yes	Every 3 years	Based on cumulative exposure	Average of three estimates made by B Readers to ERG.
7 Pulmonary function test	$43.26	Yes	No	No	Spirometry, including graphic record, total and timed vital capacity, expiratory flow rate measurements(s), and/or maximal voluntary ventilation.
8 Other necessary tests	$60.00	Yes	Yes	Yes	Assumed required by 10 percent of workers
Time Requirements (minutes)					
Complete occupational and health history survey and exam, including x-ray	120				Per survey and exam
Health history review and update	30				Per review
Physical exam and tests (without x-ray)	60				Per exam
Examination by pulmonary specialist	60				Per exam
Chest x-ray	60				Per x-ray
Recordkeeping (initial and periodic screening)	15				Average per screening; includes basic recordkeeping
Recordkeeping (referrals)	60				Includes time for referrals and notification of NIOSH
Separations rate (quits, layoffs, retirements)	67.1%				2002 separations rate for construction from BLS, Job Opening and Turnover Survey (JOLTS)

Table 4-32

Health Screening and Surveillance
Per Employee Unit Costs

Screening Tool	Unit Cost	Initial Screening	Periodic Screening		Comments/Assumptions
		Procedural Cost	Option 1	Option 2	
Unit Costs					
Initial screening					
Medical costs	$281.00				Medical components as specified above.
Recordkeeping	$8.83				Based on manager's wage rate, adjusted for benefits
Lost worktime	$47.17				Based on average construction worker wage, adjusted for benefits (BLS, 2000; BLS, 2003).
Check up without X-ray					
Medical costs	$143.77				Medical components as specified above.
Recordkeeping	$8.83				Based on manager's wage rate, adjusted for benefits
Lost worktime	$23.58				Based on average construction worker wage, adjusted for benefits (BLS, 2000; BLS, 2003).
Check up with X-ray					
Medical costs	$237.74				Medical components as specified above.
Recordkeeping	$8.83				Based on manager's wage rate, adjusted for benefits
Lost worktime	$47.17				Based on average construction worker wage, adjusted for benefits (BLS, 2000; BLS, 2003).
Examination by pulmonary specialist					
Medical costs	$253.76				Medical components as specified above.
Recordkeeping	$35.32				Based on manager's wage rate, adjusted for benefits
Lost worktime	$23.58				Based on average construction worker wage, adjusted for benefits (BLS, 2000; BLS, 2003).

Sources:
As given in Comments/Assumptions column.
Costs for examinations and tests, chest X-ray, and pulmonary tests are direct medical costs, as used in bundling services under Medicare. Costs are inflated by 30% to remove effect of discounting in Medicare reimbursement rates (Intellimed International, 2003).

Tables 4-33, 4-34, and 4-35 show the aggregate, annualized compliance costs for the health screening requirement. Costs when tri-annual x-rays are required amount to \$93.4 million for the 50 and 100 $\mu g/m^3$ PEL options and \$104.5 million for the 75 $\mu g/m^3$ PEL options. These two PEL options generate the same health screening costs because the requirements apply in both cases to workers exposed above an action level of 50 $\mu g/m^3$. Costs are higher for the PEL of 75 $\mu g/m^3$, which has an action level of 40 $\mu g/m^3$. When the scheduling of x-rays is dependent on the worker's cumulative exposures, costs of \$128.4 million are estimated for the 50 and 100 $\mu g/m^3$ PEL options and \$143.5 million for the 75 $\mu g/m^3$ PEL option.

ERG also estimated costs for the exit screenings for workers who are terminated or retire. Such workers must receive a health screening if they have not had an x-ray in the last 12 months. ERG used the BLS-estimated 2002 separations rate for construction to estimate the number of at-risk workers affected by this requirement (BLS, 2002). This rate was then adjusted to account for those who would otherwise have received an x-ray within the last year. Tables 4-36, 4-37, and 4-38 show costs of \$19.7 million under Option 1 and \$11.5 million under Option 2 for this requirement for the 50 and 100 $\mu g/m^3$ PEL options. Costs for the 75 $\mu g/m^3$ PEL option are \$22.0 million under Option 1 and \$12.8 million under option 2.

Finally, ERG estimated the cost of providing referrals to a pulmonary specialist for those employees found to have signs or symptoms of silica-related disease. Estimates in the literature suggest that between 3,400 and 7,100 new cases of silica-related diseases occur annually nationwide (Rosenman, et al., 2003). ERG used a lung-disease surveillance report published by the Centers for Disease Control and Prevention, the 2001 Annual Report on Silicosis in Michigan (NIOSH 2003; Michigan State University, 2002), and ERG's estimates of at-risk workers in construction and general industry to develop an estimate of the annual number of such silica disease cases in the construction industry. Using the midpoint of the resultant range, ERG estimated that 1,285 silica-disease cases occur annually among currently employed construction workers. ERG then distributed these disease cases among industries in proportion to the number of at-risk workers. As shown in Table 4-39, applying the unit cost of \$312.66 for a referral to a pulmonary specialist, including the associated lost work time and record keeping costs, results in a total cost \$0.4 million. The recordkeeping cost for this task includes the value of time necessary to facilitate the referral and to notify NIOSH as required by the standard.

Table 4-33

Initial and Periodic Health Screening
Annualized Costs of Health Screening, Construction Industry: PEL Option = 50, Action Level = 50
(Applied to All Adjusted At-Risk Workers Above the Action Level)

NAICS	Industry Title	Adusted At-Risk Workers Above the Action Level	At-Risk Workers Not Yet Receiving Screenings [a]	Initial Screening [b]			Periodic Screening						Total Option 1 Costs	Total Option 2 Costs
							Option 1 [d]			Option 2 [e]				
				Medical Tests	Lost Work Time [c]	Total	Medical Tests	Lost Work Time [c]	Total	Medical Tests	Lost Work Time [c]	Total		
2331	Land subdivision & land development	394	342	$13,667	$2,723	$16,390	$42,389	$9,707	$52,096	$63,058	$14,662	$77,720	$68,487	$94,111
2332	Residential building construction	23,930	20,723	$829,092	$165,213	$994,305	$2,571,468	$588,878	$3,160,347	$3,825,312	$889,478	$4,714,789	$4,154,651	$5,709,094
2333	Nonresidential building construction	83,512	72,321	$2,893,439	$576,575	$3,470,014	$8,974,142	$2,055,121	$11,029,263	$13,349,918	$3,104,179	$16,454,097	$14,499,278	$19,924,112
2341	Highway, street, bridge & tunnel construction	44,649	37,371	$1,495,165	$297,942	$1,793,107	$4,637,329	$1,061,970	$5,699,299	$6,898,482	$1,604,064	$8,502,546	$7,492,406	$10,295,653
2349	Other heavy construction	45,038	37,697	$1,508,200	$300,539	$1,808,738	$4,677,755	$1,071,228	$5,748,983	$6,958,620	$1,618,048	$8,576,668	$7,557,722	$10,385,406
2351	Plumbing, heating & AC contractor	3,373	3,289	$131,590	$26,222	$157,812	$408,133	$93,464	$501,597	$607,137	$141,174	$748,311	$659,409	$906,123
2352	Painting & wall covering contractors	751	732	$29,301	$5,839	$35,139	$90,877	$20,811	$111,689	$135,189	$31,435	$166,624	$146,828	$201,763
2353	Electrical contractors	1,650	1,609	$64,377	$12,828	$77,206	$199,670	$45,725	$245,395	$297,028	$69,066	$366,094	$322,601	$443,300
2354	Masonry, drywall, insulation, tile contractors	162,472	158,410	$6,337,724	$1,262,918	$7,600,642	$19,656,762	$4,501,492	$24,158,254	$29,241,365	$6,799,325	$36,040,690	$31,758,896	$43,641,332
2355	Carpentry & floor contractors	6,099	5,946	$237,901	$47,407	$285,307	$737,862	$168,974	$906,835	$1,097,642	$255,228	$1,352,870	$1,192,143	$1,638,177
2356	Roofing, siding, & sheet metal contractors	935	911	$36,458	$7,265	$43,723	$113,076	$25,895	$138,971	$168,212	$39,113	$207,325	$182,694	$251,048
2357	Concrete contractors	87,451	85,264	$3,411,285	$679,767	$4,091,052	$10,580,268	$2,422,932	$13,003,200	$15,739,189	$3,659,742	$19,398,931	$17,094,252	$23,489,983
2358	Water well drilling contractors	5,688	5,546	$221,891	$44,216	$266,107	$688,206	$157,602	$845,808	$1,023,774	$238,052	$1,261,826	$1,111,916	$1,527,933
2359	Other special trade contractors	36,788	35,868	$1,435,013	$285,955	$1,720,968	$4,450,764	$1,019,246	$5,470,010	$6,620,949	$1,539,531	$8,160,480	$7,190,978	$9,881,448
	Total	502,730	466,031	$18,645,103	$3,715,409	$22,360,512	$57,828,700	$13,243,048	$71,071,748	$86,025,874	$20,003,098	$106,028,972	$93,432,260	$128,389,484

Sources and notes:
[a] Workers requiring screening derived from estimates of workers not currently receiving chest x-rays (NIOSH, 1988).
[b] Annualized at 7.0 percent over ten years. Includes costs for new industry hires.
[c] Includes value of employee time for physical exam and x-ray and for recordkeeping by manager.
[d] X-ray required every three years.
[e] X-ray freqency dependent on cumulative exposure.

Table 4-34

Health Screenings
Annualized Costs of Health Screening, Construction Industry: PEL Option = 75, Action Level = 40
(Applied to All Adjusted At-Risk Workers Above the Action Level)

NAICS	Industry Title	Adusted At-Risk Workers Above the Action Level	At-Risk Workers Not Yet Receiving Screenings [a]	Initial Screening [b] Medical Tests	Initial Screening [b] Lost Work Time [c]	Initial Screening [b] Total	Periodic Screening Option 1 [d] Medical Tests	Periodic Screening Option 1 [d] Lost Work Time [c]	Periodic Screening Option 1 [d] Total	Periodic Screening Option 2 [e] Medical Tests	Periodic Screening Option 2 [e] Lost Work Time [c]	Periodic Screening Option 2 [e] Total	Total Option 1 Costs	Total Option 2 Costs
2331	Land subdivision & land development	457	396	$15,840	$3,156	$18,996	$49,128	$11,251	$60,379	$73,083	$16,994	$90,077	$79,375	$109,073
2332	Residential building construction	26,964	23,351	$934,237	$186,165	$1,120,403	$2,897,583	$663,560	$3,561,143	$4,310,440	$1,002,282	$5,312,721	$4,681,546	$6,433,124
2333	Nonresidential building construction	92,726	80,300	$3,212,680	$640,191	$3,852,871	$9,964,284	$2,281,869	$12,246,153	$14,822,852	$3,446,672	$18,269,524	$16,099,024	$22,122,395
2341	Highway, street, bridge & tunnel construction	50,518	42,283	$1,691,690	$337,103	$2,028,793	$5,246,858	$1,201,556	$6,448,414	$7,805,217	$1,814,902	$9,620,119	$8,477,206	$11,648,912
2349	Other heavy construction	51,847	43,396	$1,736,204	$345,973	$2,082,178	$5,384,923	$1,233,173	$6,618,096	$8,010,602	$1,862,659	$9,873,260	$8,700,273	$11,955,438
2351	Plumbing, heating & AC contractor	3,834	3,738	$149,560	$29,803	$179,363	$463,869	$106,228	$570,097	$690,051	$160,453	$850,504	$749,460	$1,029,867
2352	Painting & wall covering contractors	861	840	$33,590	$6,693	$40,283	$104,181	$23,858	$128,038	$154,979	$36,036	$191,015	$168,322	$231,299
2353	Electrical contractors	1,869	1,822	$72,888	$14,524	$87,412	$226,066	$51,770	$277,836	$336,295	$78,197	$414,491	$365,248	$501,904
2354	Masonry, drywall, insulation, tile contractors	184,529	179,916	$7,198,114	$1,434,368	$8,632,482	$22,325,304	$5,112,601	$27,437,905	$33,211,083	$7,722,381	$40,933,464	$36,070,387	$49,565,946
2355	Carpentry & floor contractors	7,225	7,044	$281,819	$56,158	$337,977	$874,074	$200,167	$1,074,241	$1,300,271	$302,345	$1,602,616	$1,412,218	$1,940,592
2356	Roofing, siding, & sheet metal contractors	1,055	1,029	$41,164	$8,203	$49,367	$127,672	$29,237	$156,909	$189,925	$44,162	$234,087	$206,276	$283,453
2357	Concrete contractors	91,885	89,588	$3,584,264	$714,236	$4,298,500	$11,116,769	$2,545,793	$13,662,563	$16,537,287	$3,845,320	$20,382,606	$17,961,062	$24,681,106
2358	Water well drilling contractors	6,376	6,216	$248,699	$49,558	$298,258	$771,353	$176,643	$947,996	$1,147,463	$266,813	$1,414,276	$1,246,254	$1,712,534
2359	Other special trade contractors	42,197	41,142	$1,646,019	$328,002	$1,974,021	$5,105,208	$1,169,117	$6,274,325	$7,594,499	$1,765,905	$9,360,403	$8,248,346	$11,334,424
Total		562,342	521,061	$20,846,768	$4,154,135	$25,000,902	$64,657,271	$14,806,824	$79,464,095	$96,184,046	$22,365,119	$118,549,165	$104,464,998	$143,550,067

Sources and notes:
[a] Workers requiring screening derived from estimates of workers not currently receiving chest x-rays (NIOSH, 1988).
[b] Annualized at 7.0 percent over ten years. Includes costs for new industry hires.
[c] Includes value of employee time for physical exam and x-ray and for recordkeeping by manager.
[d] X-ray required every three years.
[e] X-ray freqency dependent on cumulative exposure.

Table 4-35

Health Screenings
Annualized Costs of Health Screening, Construction Industry: PEL Option = 100, Action Level = 50
(Applied to All Adjusted At-Risk Workers Above the Action Level)

NAICS Industry Title	Adjusted At-Risk Workers Above the Action Level	At-Risk Workers Not Yet Receiving Screenings [a]	Initial Screening [b] Medical Tests	Initial Screening [b] Lost Work Time [c]	Initial Screening [b] Total	Periodic Screening Option 1 [d] Medical Tests	Periodic Screening Option 1 [d] Lost Work Time [c]	Periodic Screening Option 1 [d] Total	Periodic Screening Option 2 [e] Medical Tests	Periodic Screening Option 2 [e] Lost Work Time [c]	Periodic Screening Option 2 [e] Total	Total Option 1 Costs	Total Option 2 Costs
2331 Land subdivision & land development	394	342	$13,667	$2,723	$16,390	$42,389	$9,707	$52,096	$63,058	$14,662	$77,720	$68,487	$94,111
2332 Residential building construction	23,930	20,723	$829,092	$165,213	$994,305	$2,571,468	$588,878	$3,160,347	$3,825,312	$889,478	$4,714,789	$4,154,651	$5,709,094
2333 Nonresidential building construction	83,512	72,321	$2,893,439	$576,575	$3,470,014	$8,974,142	$2,055,121	$11,029,263	$13,349,918	$3,104,179	$16,454,097	$14,499,278	$19,924,112
2341 Highway, street, bridge & tunnel construction	44,649	37,371	$1,495,165	$297,942	$1,793,107	$4,637,329	$1,061,970	$5,699,299	$6,898,482	$1,604,064	$8,502,546	$7,492,406	$10,295,653
2349 Other heavy construction	45,038	37,697	$1,508,200	$300,539	$1,808,738	$4,677,755	$1,071,228	$5,748,983	$6,958,620	$1,618,048	$8,576,668	$7,557,722	$10,385,406
2351 Plumbing, heating & AC contractor	3,373	3,289	$131,590	$26,222	$157,812	$408,133	$93,464	$501,597	$607,137	$141,174	$748,311	$659,409	$906,123
2352 Painting & wall covering contractors	751	732	$29,301	$5,839	$35,139	$90,877	$20,811	$111,689	$135,189	$31,435	$166,624	$146,828	$201,763
2353 Electrical contractors	1,650	1,609	$64,377	$12,828	$77,206	$199,670	$45,725	$245,395	$297,028	$69,066	$366,094	$322,601	$443,300
2354 Masonry, drywall, insulation, tile contractors	162,472	158,410	$6,337,724	$1,262,918	$7,600,642	$19,656,762	$4,501,492	$24,158,254	$29,241,365	$6,799,325	$36,040,690	$31,758,896	$43,641,332
2355 Carpentry & floor contractors	6,099	5,946	$237,901	$47,407	$285,307	$737,862	$168,974	$906,835	$1,097,642	$255,228	$1,352,870	$1,192,143	$1,638,177
2356 Roofing, siding, & sheet metal contractors	935	911	$36,458	$7,265	$43,723	$113,076	$25,895	$138,971	$168,212	$39,113	$207,325	$182,694	$251,048
2357 Concrete contractors	87,451	85,264	$3,411,285	$679,767	$4,091,052	$10,580,268	$2,422,932	$13,003,200	$15,739,189	$3,659,742	$19,398,931	$17,094,252	$23,489,983
2358 Water well drilling contractors	5,688	5,546	$221,891	$44,216	$266,107	$688,206	$157,602	$845,808	$1,023,774	$238,052	$1,261,826	$1,111,916	$1,527,933
2359 Other special trade contractors	36,788	35,868	$1,435,013	$285,955	$1,720,968	$4,450,764	$1,019,246	$5,470,010	$6,620,949	$1,539,531	$8,160,480	$7,190,978	$9,881,448
Total	502,730	466,031	$18,645,103	$3,715,409	$22,360,512	$57,828,700	$13,243,048	$71,071,748	$86,025,874	$20,003,098	$106,028,972	$93,432,260	$128,389,484

Sources and notes:
[a] Workers requiring screening derived from estimates of workers not currently receiving chest x-rays (NIOSH, 1988).
[b] Annualized at 7.0 percent over ten years. Includes costs for new industry hires.
[c] Includes value of employee time for physical exam and x-ray and for recordkeeping by manager.
[d] X-ray required every three years.
[e] X-ray freqency dependent on cumulative exposure.

Table 4-36

Termination and Retirement Health Screening
Annualized Costs of Health Screening, Construction Industry: PEL Option = 50, Action Level = 50
(Applied to All Adjusted At-Risk Workers Above the Action Level)

NAICS	Industry Title	Adusted At-Risk Workers Above the Action Level	Option 1 [c] Workers Needing Screenings [a]	Option 1 [c] Medical Tests	Option 1 [c] Lost Work Time [b]	Option 1 [c] Total	Option 2 [d] Workers Needing Screenings [a]	Option 2 [d] Medical Tests	Option 2 [d] Lost Work Time [c]	Option 2 [d] Total
2331	Land subdivision & land development	394	153	$9,474	$4,953	$14,427	89	$5,521	$2,886	$8,408
2332	Residential building construction	23,930	9,270	$574,745	$300,462	$875,207	5,402	$334,940	$175,098	$510,037
2333	Nonresidential building construction	83,512	32,352	$2,005,799	$1,048,579	$3,054,377	18,853	$1,168,903	$611,072	$1,779,975
2341	Highway, street, bridge & tunnel construction	44,649	16,717	$1,036,483	$541,846	$1,578,329	9,742	$604,023	$315,767	$919,790
2349	Other heavy construction	45,038	16,863	$1,045,519	$546,570	$1,592,088	9,827	$609,289	$318,520	$927,809
2351	Plumbing, heating & AC contractor	3,373	1,471	$91,221	$47,688	$138,909	857	$53,160	$27,791	$80,951
2352	Painting & wall covering contractors	751	328	$20,312	$10,619	$30,930	191	$11,837	$6,188	$18,025
2353	Electrical contractors	1,650	720	$44,628	$23,330	$67,958	419	$26,007	$13,596	$39,603
2354	Masonry, drywall, insulation, tile contractors	162,472	70,862	$4,393,457	$2,296,783	$6,690,240	41,296	$2,560,339	$1,338,478	$3,898,817
2355	Carpentry & floor contractors	6,099	2,660	$164,918	$86,215	$251,133	1,550	$96,108	$50,243	$146,351
2356	Roofing, siding, & sheet metal contractors	935	408	$25,274	$13,212	$38,486	238	$14,728	$7,700	$22,428
2357	Concrete contractors	87,451	38,142	$2,364,782	$1,236,245	$3,601,027	22,227	$1,378,105	$720,437	$2,098,542
2358	Water well drilling contractors	5,688	2,481	$153,820	$80,413	$234,233	1,446	$89,640	$46,862	$136,502
2359	Other special trade contractors	36,788	16,045	$994,784	$520,047	$1,514,831	9,350	$579,722	$303,064	$882,786
	Total	502,730	208,471	$12,925,217	$6,756,962	$19,682,178	121,489	$7,532,324	$3,937,700	$11,470,024

Sources and notes:
[a] Workers requiring screening derived from estimates of workers not currently receiving chest x-rays (NIOSH, 1988). Adjusted for workers who overwise would have recieving a screening in a given year
[b] Includes value of employee time for physical exam and x-ray and for recordkeeping by manager.
[c] X-ray required every three years.
[d] X-ray freqency dependent on cumulative exposure.

Table 4-37

Termination and Retirement Health Screening
Annualized Costs of Health Screening, Construction Industry: PEL Option = 75, Action Level = 40
(Applied to All Adjusted At-Risk Workers Above the Action Level)

NAICS	Industry Title	Adusted At-Risk Workers Above the Action Level	Option 1 [c]				Option 2 [d]			
			Workers Needing Screenings [a]	Medical Tests	Lost Work Time [b]	Total	Workers Needing Screenings [a]	Medical Tests	Lost Work Time [c]	Total
2331	Land subdivision & land development	457	177	$10,981	$5,740	$16,721	103	$6,399	$3,345	$9,744
2332	Residential building construction	26,964	10,446	$647,635	$338,566	$986,201	6,087	$377,417	$197,304	$574,721
2333	Nonresidential building construction	92,726	35,921	$2,227,104	$1,164,271	$3,391,375	20,933	$1,297,871	$678,493	$1,976,364
2341	Highway, street, bridge & tunnel construction	50,518	18,915	$1,172,718	$613,066	$1,785,785	11,023	$683,416	$357,272	$1,040,687
2349	Other heavy construction	51,847	19,413	$1,203,577	$629,198	$1,832,775	11,313	$701,399	$366,673	$1,068,072
2351	Plumbing, heating & AC contractor	3,834	1,672	$103,679	$54,201	$157,879	975	$60,420	$31,586	$92,006
2352	Painting & wall covering contractors	861	376	$23,285	$12,173	$35,458	219	$13,570	$7,094	$20,664
2353	Electrical contractors	1,869	815	$50,528	$26,415	$76,942	475	$29,446	$15,393	$44,839
2354	Masonry, drywall, insulation, tile contractors	184,529	80,482	$4,989,899	$2,608,587	$7,598,487	46,902	$2,907,923	$1,520,185	$4,428,109
2355	Carpentry & floor contractors	7,225	3,151	$195,363	$102,131	$297,494	1,836	$113,850	$59,518	$173,368
2356	Roofing, siding, & sheet metal contractors	1,055	460	$28,536	$14,918	$43,454	268	$16,630	$8,694	$25,323
2357	Concrete contractors	91,885	40,076	$2,484,694	$1,298,933	$3,783,627	23,355	$1,447,985	$756,968	$2,204,954
2358	Water well drilling contractors	6,376	2,781	$172,404	$90,128	$262,532	1,620	$100,471	$52,523	$152,994
2359	Other special trade contractors	42,197	18,404	$1,141,058	$596,515	$1,737,573	10,725	$664,965	$347,626	$1,012,592
	Total	562,342	233,088	$14,451,462	$7,554,842	$22,006,304	135,835	$8,421,762	$4,402,675	$12,824,436

Sources and notes:
[a] Workers requiring screening derived from estimates of workers not currently receiving chest x-rays (NIOSH, 1988). Adjusted for workers who overwise would have recieving a screening in a given year
[b] Includes value of employee time for physical exam and x-ray and for recordkeeping by manager.
[c] X-ray required every three years.
[d] X-ray freqency dependent on cumulative exposure.

Table 4-38

Termination and Retirement Health Screening
Annualized Costs of Health Screening, Construction Industry: PEL Option = 100, Action Level = 50
(Applied to All Adjusted At-Risk Workers Above the Action Level)

NAICS	Industry Title	Adusted At-Risk Workers Above the Action Level	Option 1 [c] Workers Needing Screenings [a]	Option 1 [c] Medical Tests	Option 1 [c] Lost Work Time [b]	Option 1 [c] Total	Option 2 [d] Workers Needing Screenings [a]	Option 2 [d] Medical Tests	Option 2 [d] Lost Work Time [c]	Option 2 [d] Total
2331	Land subdivision & land development	394	153	$9,474	$4,953	$14,427	89	$5,521	$2,886	$8,408
2332	Residential building construction	23,930	9,270	$574,745	$300,462	$875,207	5,402	$334,940	$175,098	$510,037
2333	Nonresidential building construction	83,512	32,352	$2,005,799	$1,048,579	$3,054,377	18,853	$1,168,903	$611,072	$1,779,975
2341	Highway, street, bridge & tunnel construction	44,649	16,717	$1,036,483	$541,846	$1,578,329	9,742	$604,023	$315,767	$919,790
2349	Other heavy construction	45,038	16,863	$1,045,519	$546,570	$1,592,088	9,827	$609,289	$318,520	$927,809
2351	Plumbing, heating & AC contractor	3,373	1,471	$91,221	$47,688	$138,909	857	$53,160	$27,791	$80,951
2352	Painting & wall covering contractors	751	328	$20,312	$10,619	$30,930	191	$11,837	$6,188	$18,025
2353	Electrical contractors	1,650	720	$44,628	$23,330	$67,958	419	$26,007	$13,596	$39,603
2354	Masonry, drywall, insulation, tile contractors	162,472	70,862	$4,393,457	$2,296,783	$6,690,240	41,296	$2,560,339	$1,338,478	$3,898,817
2355	Carpentry & floor contractors	6,099	2,660	$164,918	$86,215	$251,133	1,550	$96,108	$50,243	$146,351
2356	Roofing, siding, & sheet metal contractors	935	408	$25,274	$13,212	$38,486	238	$14,728	$7,700	$22,428
2357	Concrete contractors	87,451	38,142	$2,364,782	$1,236,245	$3,601,027	22,227	$1,378,105	$720,437	$2,098,542
2358	Water well drilling contractors	5,688	2,481	$153,820	$80,413	$234,233	1,446	$89,640	$46,862	$136,502
2359	Other special trade contractors	36,788	16,045	$994,784	$520,047	$1,514,831	9,350	$579,722	$303,064	$882,786
	Total	502,730	208,471	$12,925,217	$6,756,962	$19,682,178	121,489	$7,532,324	$3,937,700	$11,470,024

Sources and notes:
[a] Workers requiring screening derived from estimates of workers not currently receiving chest x-rays (NIOSH, 1988). Adjusted for workers who overwise would have recieving a screening in a given year
[b] Includes value of employee time for physical exam and x-ray and for recordkeeping by manager.
[c] X-ray required every three years.
[d] X-ray freqency dependent on cumulative exposure.

Table 4-39

Medical Referrals to a Pulmonary Specialist
Annualized Costs, Construction Industry

NAICS	Industry Title	Adusted At-Risk Workers [a]	Estimated Annual Silicosis Disease Cases [b]	Annual Costs
2331	Land subdivision & land development	394	1	$315
2332	Residential building construction	23,930	61	$19,124
2333	Nonresidential building construction	83,512	213	$66,739
2341	Highway, street, bridge & tunnel construction	44,649	114	$35,682
2349	Other heavy construction	45,038	115	$35,993
2351	Plumbing, heating & AC contractor	3,373	9	$2,696
2352	Painting & wall covering contractors	751	2	$600
2353	Electrical contractors	1,650	4	$1,319
2354	Masonry, drywall, insulation, tile contractors	162,472	415	$129,841
2355	Carpentry & floor contractors	6,099	16	$4,874
2356	Roofing, siding, & sheet metal contractors	935	2	$747
2357	Concrete contractors	87,451	224	$69,887
2358	Water well drilling contractors	5,688	15	$4,546
2359	Other special trade contractors	36,788	94	$29,399
	Total	502,730	1,285	$401,762

[a] Estimated number of workers currently exposed above 50 micrograms per cubic meter (see Table 4-22).
[b] Assumes silicosis cases are distributed among industries in proportion to the number of at-risk workers exposed above the PEL.

Overall health screening costs for both the 50 μg/m^3 and 100 μg/m^3 PELs total $113.5 million using option 1 for periodic screening and $140.3 under option 2. For the 75 μg/m^3 PEL, costs are $126.9 million per year (option 1) and $156.8 million per year (option 2). OSHA also considered the separate impact of exit screening requirements on the total costs. If the exit screening requirements are removed, total annual health screening costs fall to $93.8 million and $129.0 million per year under periodic screening options 1 and 2 for the PEL options of 50 μg/m^3 and 100 μg/m^3. For the 75 μg/m^3 PEL, annual costs are $104.9 million and $144.0 million.

4.8.6 Information and Training

The draft standard requires a training program for all workers likely exposed above the action level who perform activities listed in Table 1. Training classes on reducing silica exposures are expected to be conducted by outside consulting trainers who will provide (for subsequent study and/or viewing) training materials and videos. ERG judged that establishments could purchase sufficient training materials at an average cost of $2 per worker, encompassing the cost of handouts, video presentations, and training manuals and exercises. ERG included the value of worker and trainer time as measured by wages and benefits in the cost estimates. The unit costs of training are defined in Table 4-40.

ERG applied the unit training cost to the total adjusted at-risk workers. Because the standard requires annual training, no additional training costs were estimated for new hires. The construction industry has a high turnover rate and many newly hired workers would have received training from their previous employer.

ERG also considered whether current training programs adequately address silica hazards. For example, ERG examined the NOES data on training rates, as measured at that time (NIOSH, 1988). In the NOES survey results, an average 41 percent of employees received training under a formal program. For compliance with the silica program requirements, however, ERG judged that incremental training resources will be needed for all affected workers. Thus, the inclusion of silica hazards into existing programs lengthens those programs. Therefore, no cost adjustment was made to represent any current compliance with silica training requirements.

Table 4-40

Information and Training
Per Employee Unit Costs

Item	Unit Cost	Cost Per Employee	Comments/Assumptions
Direct Costs			
Hourly Cost of trainer teaching	$75.00	$15.00	ERG estimated the trainer's wage at $75 per hour. Class size assumed at 5.
Materials for class	$2.00	$2.00	Estimated cost of $2 per worker for the training/reading materials.
Total		$17.00	
Labor Costs (minutes)			
Time spent in class	120	NA	ERG estimated that average training sessions last 2 hours.

Sources:
As given in Comments/Assumptions column.

Tables 4-41, 4-42, and 4-43 present the training costs under the three PELs considered. As for other selected other program provisions, costs for the 50 $\mu g/m^3$ and the 100 $\mu g/m^3$ PELs are equivalent, while costs for the 75 $\mu g/m^3$ PEL are somewhat higher due to the lower associated action level. For the 50 $\mu g/m^3$ and the 100 $\mu g/m^3$ PELs, annual costs are $39.8 million. For the 75 $\mu g/m^3$ PEL, annual costs are $44.5 million.

4.8.7 Abrasive Blasting

ERG also estimated program compliance for construction industry abrasive blasters. These estimates embody the same assumptions and unit costs described above. ERG also estimated costs for other specific blasting requirements, including the evaluation of alternative media, restrictions against use of compressed air for cleaning, and the prohibition of silica media when blasting in enclosed areas.

Table 4-44 presents these costs. Annual program costs for abrasive blasters range from $18.2 to $19.1 million, depending on the program alternatives and the PEL option. The abrasive blasting requirements in the draft standard impose no engineering control restrictions on blasting operations so no estimates of control costs are presented.

4.8.8 Program Cost Summary

Table 4-45 presents a summary of the annual program costs (exclusive of respirator costs) for each regulatory option. In each case the costs reflecting the most expensive and least expensive regulatory options are shown. Total program costs range from $224.8 million (least expensive combination; 100 $\mu g/m^3$ PEL option) to $290.0 million (most expensive combination; 75 $\mu g/m^3$ PEL option.)

Table 4-41

Information and Training
Annual Costs, Construction Industry: PEL Option = 50, Action Level = 50
(Applied to Adjusted FTE Workers Exposed Above the Action Level)

NAICS	Industry Title	Workers Needing Training	Direct Costs: Trainer's Fee	Direct Costs: Class Materials	Direct Costs: Total	Labor Costs: Class Time	Total
2331	Land subdivision & land development	394	$11,834	$789	$12,623	$18,605	$31,228
2332	Residential building construction	23,930	$717,887	$47,859	$765,746	$1,128,671	$1,894,416
2333	Nonresidential building construction	83,512	$2,505,346	$167,023	$2,672,369	$3,938,936	$6,611,306
2341	Highway, street, bridge & tunnel construction	44,649	$1,339,477	$89,298	$1,428,775	$2,105,942	$3,534,717
2349	Other heavy construction	45,038	$1,351,154	$90,077	$1,441,230	$2,124,300	$3,565,531
2351	Plumbing, heating & AC contractor	3,373	$101,202	$6,747	$107,949	$159,111	$267,060
2352	Painting & wall covering contractors	751	$22,534	$1,502	$24,037	$35,429	$59,465
2353	Electrical contractors	1,650	$49,511	$3,301	$52,812	$77,841	$130,653
2354	Masonry, drywall, insulation, tile contractors	162,472	$4,874,163	$324,944	$5,199,107	$7,663,220	$12,862,327
2355	Carpentry & floor contractors	6,099	$182,963	$12,198	$195,160	$287,656	$482,817
2356	Roofing, siding, & sheet metal contractors	935	$28,039	$1,869	$29,908	$44,083	$73,991
2357	Concrete contractors	87,451	$2,623,522	$174,901	$2,798,424	$4,124,734	$6,923,158
2358	Water well drilling contractors	5,688	$170,650	$11,377	$182,027	$268,298	$450,325
2359	Other special trade contractors	36,788	$1,103,628	$73,575	$1,177,203	$1,735,137	$2,912,340
	Total	502,730	$15,081,909	$1,005,461	$16,087,370	$23,711,965	$39,799,335

Table 4-42

Information and Training
Annual Costs, Construction Industry: PEL Option = 75, Action Level = 40
(Applied to Adjusted FTE Workers Exposed Above the Action Level)

NAICS	Industry Title	Workers Needing Training	Direct Costs: Trainer's Fee	Direct Costs: Class Materials	Direct Costs: Total	Labor Costs: Class Time	Total
2331	Land subdivision & land development	457	$13,715	$914	$14,630	$21,563	$36,193
2332	Residential building construction	26,964	$808,930	$53,929	$862,858	$1,271,809	$2,134,667
2333	Nonresidential building construction	92,726	$2,781,768	$185,451	$2,967,219	$4,373,530	$7,340,750
2341	Highway, street, bridge & tunnel construction	50,518	$1,515,537	$101,036	$1,616,573	$2,382,746	$3,999,319
2349	Other heavy construction	51,847	$1,555,417	$103,694	$1,659,111	$2,445,445	$4,104,556
2351	Plumbing, heating & AC contractor	3,834	$115,023	$7,668	$122,691	$180,840	$303,531
2352	Painting & wall covering contractors	861	$25,833	$1,722	$27,555	$40,615	$68,170
2353	Electrical contractors	1,869	$56,056	$3,737	$59,793	$88,132	$147,925
2354	Masonry, drywall, insulation, tile contractors	184,529	$5,535,865	$369,058	$5,904,922	$8,703,555	$14,608,477
2355	Carpentry & floor contractors	7,225	$216,739	$14,449	$231,188	$340,759	$571,947
2356	Roofing, siding, & sheet metal contractors	1,055	$31,658	$2,111	$33,769	$49,773	$83,542
2357	Concrete contractors	91,885	$2,756,555	$183,770	$2,940,326	$4,333,890	$7,274,216
2358	Water well drilling contractors	6,376	$191,267	$12,751	$204,019	$300,713	$504,732
2359	Other special trade contractors	42,197	$1,265,906	$84,394	$1,350,300	$1,990,273	$3,340,573
	Total	562,342	$16,870,269	$1,124,685	$17,994,953	$26,523,646	$44,518,599

Table 4-43
Information and Training
Annual Costs, Construction Industry: PEL Option = 100, *Action Level* = 50
(Applied to Adjusted FTE Workers Exposed Above the Action Level)

			Direct Costs			Labor Costs	
NAICS	Industry Title	Workers Needing Training	Trainer's Fee	Class Materials	Total	Class Time	Total
2331	Land subdivision & land development	394	$11,834	$789	$12,623	$18,605	$31,228
2332	Residential building construction	23,930	$717,887	$47,859	$765,746	$1,128,671	$1,894,416
2333	Nonresidential building construction	83,512	$2,505,346	$167,023	$2,672,369	$3,938,936	$6,611,306
2341	Highway, street, bridge & tunnel construction	44,649	$1,339,477	$89,298	$1,428,775	$2,105,942	$3,534,717
2349	*Other heavy construction*	45,038	$1,351,154	$90,077	$1,441,230	$2,124,300	$3,565,531
2351	Plumbing, heating & AC contractor	3,373	$101,202	$6,747	$107,949	$159,111	$267,060
2352	Painting & wall covering contractors	751	$22,534	$1,502	$24,037	$35,429	$59,465
2353	Electrical contractors	1,650	$49,511	$3,301	$52,812	$77,841	$130,653
2354	Masonry, drywall, insulation, tile contractors	162,472	$4,874,163	$324,944	$5,199,107	$7,663,220	$12,862,327
2355	Carpentry & floor contractors	6,099	$182,963	$12,198	$195,160	$287,656	$482,817
2356	Roofing, siding, & sheet metal contractors	935	$28,039	$1,869	$29,908	$44,083	$73,991
2357	Concrete contractors	87,451	$2,623,522	$174,901	$2,798,424	$4,124,734	$6,923,158
2358	Water well drilling contractors	5,688	$170,650	$11,377	$182,027	$268,298	$450,325
2359	Other special trade contractors	36,788	$1,103,628	$73,575	$1,177,203	$1,735,137	$2,912,340
	Total	502,730	$15,081,909	$1,005,461	$16,087,370	$23,711,965	$39,799,335

Table 4-44

Silica Program Costs for Abrasive Blasters

Program Requirements	Painting & Wall Covering Contractors (NAICS 2352)	Other Special Trade Contractors (NAICS 2359)	Total
Number of blasters	8,521	3,199	11,720
Establishments with blasters [a]	852	320	1,172
Evaluate alternatives to silica media [b]	$57,988	$21,773	$79,761
Maintain records of evaluation [c]	$6,816	$2,559	$9,376
Prohibition on use of dry silica sand with over 1 percent silica in enclosed areas [d]	$7,242,436	$2,719,423	$9,961,859
Health screening			
Option 1	$1,708,235	$641,416	$2,349,652
Option 2	$2,347,363	$881,399	$3,228,762
Training	$674,538	$253,279	$927,817
Regulated areas	$1,696,061	$636,845	$2,332,906
Hygiene requirements	$1,847,848	$693,838	$2,541,687
Total - least expensive options	$13,233,923	$4,969,134	$18,203,057
Total - most expensive options	$13,873,051	$5,209,117	$19,082,168

[a] Assumes 10 abrasive blasters per establishment.
[b] Estimated $478 one time cost per establishment, annualized over ten years.
[c] Estimated $8 annual cost per establishment.
[d] Based on estimated $0.16 differential per square foot of blast area for non-silica media (NIOSH, 1998), average daily crew output, and an estimated 5.0 percent of work performed in enclosed area

Table 4-45

Summary of Annual Costs for Crystalline Silica Programs, Construction Industry

NAICS	Industry	PEL = 50		PEL = 75		PEL = 100	
		Least Expensive Options	Most Expensive Options	Least Expensive Options	Most Expensive Options	Least Expensive Options	Most Expensive Options
2331	Land subdivision & land development	$181,456	$201,060	$195,512	$226,480	$168,227	$196,707
2332	Residential building construction	$11,396,514	$12,585,787	$11,895,704	$13,749,011	$10,367,897	$12,058,128
2333	Nonresidential building construction	$31,666,401	$35,816,833	$34,672,101	$40,559,671	$31,063,858	$36,639,341
2341	Highway, street, bridge & tunnel construction	$18,929,608	$21,074,316	$20,547,161	$23,667,793	$17,935,482	$20,956,385
2349	Other heavy construction	$20,735,656	$22,899,061	$22,220,335	$25,539,845	$19,137,458	$22,252,057
2351	Plumbing, heating & AC contractor	$1,685,934	$1,874,690	$1,799,335	$2,070,833	$1,569,407	$1,822,839
2352	Painting & wall covering contractors [a]	$13,625,510	$14,306,667	$13,649,519	$14,352,627	$13,588,681	$14,285,402
2353	Electrical contractors	$823,417	$915,762	$876,432	$1,008,301	$768,145	$892,178
2354	Masonry, drywall, insulation, tile contractors	$69,535,185	$78,626,198	$76,946,900	$89,543,382	$67,155,494	$78,428,358
2355	Carpentry & floor contractors	$2,899,572	$3,240,824	$3,099,501	$3,725,166	$2,622,517	$3,146,308
2356	Roofing, siding, & sheet metal contractors	$468,774	$521,071	$487,823	$568,926	$432,401	$504,560
2357	Concrete contractors	$35,849,243	$40,742,488	$37,352,926	$43,054,987	$34,870,390	$40,942,578
2358	Water well drilling contractors	$3,605,438	$3,923,725	$3,565,176	$4,015,849	$3,115,830	$3,534,238
2359	Other special trade contractors [a]	$23,319,732	$25,618,139	$24,649,516	$27,903,204	$21,956,099	$25,001,165
	Total	$234,722,440	$262,346,621	$251,957,941	$289,986,075	$224,751,887	$260,660,244

[a] Includes program costs for abrasive blasters.

4.9 TOTAL COST SUMMARY

Table 4-46, 4-47, and 4-48 summarize the technical control costs and program costs (including respirator costs) for the construction industry for the three PELs under consideration. Referring only to the lowest cost program options, the total annual costs are \$654.6 million, \$625.6 million, and \$521.8 million for the 50, 75, and 100 $\mu g/m^3$ PEL options, respectively. Costs are highest for the masonry, drywall, insulation, and tile contractors industry (\$203.3 million per year) and then for the concrete contractors industry (\$107.7 million per year) for the least expensive 50 $\mu g/m^3$ PEL option.

Table 4-46

Summary of Combined Costs for Program Elements, Controls, and Respirators
Construction Industry, PEL Option=50

NAICS	Industry	Control Costs	Respirator Costs	Program Costs		Total Costs	
				Least Expensive Options	Most Expensive Options	Least Expensive Options	Most Expensive Options
2331	Land subdivision & land development	$235,924	$57,014	$181,456	$201,060	$474,395	$493,999
2332	*Residential building construction*	$19,343,692	$7,149,605	$11,396,514	$12,585,787	$37,889,812	$39,079,085
2333	Nonresidential building construction	$29,981,705	$28,899,495	$31,666,401	$35,816,833	$90,547,601	$94,698,033
2341	Highway, street, bridge & tunnel construction	$26,055,172	$9,242,761	$18,929,608	$21,074,316	$54,227,541	$56,372,249
2349	Other heavy construction	$30,226,815	$8,041,039	$20,735,656	$22,899,061	$59,003,509	$61,166,914
2351	Plumbing, heating & AC contractor	$2,546,288	$770,255	$1,685,934	$1,874,690	$5,002,477	$5,191,233
2352	Painting & wall covering contractors [a]	$563,882	$254,733	$13,625,510	$14,306,667	$14,444,124	$15,125,282
2353	Electrical contractors	$1,335,520	$366,674	$823,417	$915,762	$2,525,611	$2,617,956
2354	Masonry, drywall, insulation, tile contractors	$62,086,849	$71,654,354	$69,535,185	$78,626,198	$203,276,388	$212,367,401
2355	Carpentry & floor contractors	$4,559,291	$1,044,599	$2,899,572	$3,240,824	$8,503,462	$8,844,714
2356	Roofing, siding, & sheet metal contractors	$728,239	$282,455	$468,774	$521,071	$1,479,468	$1,531,764
2357	Concrete contractors	$34,654,198	$37,207,811	$35,849,243	$40,742,488	$107,711,252	$112,604,497
2358	Water well drilling contractors	$6,535,635	$2,461,568	$3,605,438	$3,923,725	$12,602,642	$12,920,929
2359	Other special trade contractors [a]	$25,815,161	$7,792,564	$23,319,732	$25,618,139	$56,927,456	$59,225,863
	Total	$244,668,370	$175,224,928	$234,722,440	$262,346,621	$654,615,738	$682,239,919

[a] Includes program costs for abrasive blasters.

Table 4-47

Summary of Combined Costs for Program Elements, Controls, and Respirators
Construction Industry, PEL Option=75

NAICS	Industry	Control Costs	Respirator Costs	Program Costs		Total Costs	
				Least Expensive Options	Most Expensive Options	Least Expensive Options	Most Expensive Options
2331	Land subdivision & land development	$183,644	$51,603	$195,512	$226,480	$430,758	$461,726
2332	Residential building construction	$14,843,906	$6,666,956	$11,895,704	$13,749,011	$33,406,566	$35,259,873
2333	Nonresidential building construction	$25,528,044	$26,942,748	$34,672,101	$40,559,671	$87,142,892	$93,030,463
2341	Highway, street, bridge & tunnel construction	$22,750,191	$8,781,286	$20,547,161	$23,667,793	$52,078,639	$55,199,271
2349	Other heavy construction	$24,721,736	$7,114,777	$22,220,335	$25,539,845	$54,056,848	$57,376,357
2351	Plumbing, heating & AC contractor	$2,133,943	$700,666	$1,799,335	$2,070,833	$4,633,945	$4,905,442
2352	Painting & wall covering contractors [a]	$469,380	$235,931	$13,649,519	$14,352,627	$14,354,830	$15,057,938
2353	Electrical contractors	$1,119,975	$332,382	$876,432	$1,008,301	$2,328,789	$2,460,658
2354	Masonry, drywall, insulation, tile contractors	$56,887,566	$66,405,279	$76,946,900	$89,543,382	$200,239,744	$212,836,227
2355	Carpentry & floor contractors	$2,491,712	$968,218	$3,099,501	$3,725,166	$6,559,431	$7,185,096
2356	Roofing, siding, & sheet metal contractors	$526,114	$253,852	$487,823	$568,926	$1,267,789	$1,348,892
2357	Concrete contractors	$32,527,129	$35,588,447	$37,352,926	$43,054,987	$105,468,502	$111,170,563
2358	Water well drilling contractors	$5,233,422	$1,972,124	$3,565,176	$4,015,849	$10,770,722	$11,221,394
2359	Other special trade contractors [a]	$21,367,023	$6,876,697	$24,649,516	$27,903,204	$52,893,236	$56,146,924
	Total	$210,783,784	$162,890,965	$251,957,941	$289,986,075	$625,632,690	$663,660,824

[a] Includes program costs for abrasive blasters.

Table 4-48

Summary of Combined Costs for Program Elements, Controls, and Respirators
Construction Industry, PEL Option=100

NAICS	Industry	Control Costs	Respirator Costs	Program Costs		Total Costs	
				Least Expensive Options	Most Expensive Options	Least Expensive Options	Most Expensive Options
2331	Land subdivision & land development	$144,608	$44,081	$168,227	$196,707	$356,917	$385,397
2332	Residential building construction	$12,761,178	$5,080,554	$10,367,897	$12,058,128	$28,209,628	$29,899,860
2333	Nonresidential building construction	$21,775,429	$20,380,598	$31,063,858	$36,639,341	$73,219,885	$78,795,368
2341	Highway, street, bridge & tunnel construction	$18,360,059	$6,106,155	$17,935,482	$20,956,385	$42,401,697	$45,422,599
2349	Other heavy construction	$19,313,620	$5,786,289	$19,137,458	$22,252,057	$44,237,367	$47,351,965
2351	Plumbing, heating & AC contractor	$1,734,648	$580,859	$1,569,407	$1,822,839	$3,884,914	$4,138,346
2352	Painting & wall covering contractors [a]	$392,488	$167,629	$13,588,681	$14,285,402	$14,148,798	$14,845,519
2353	Electrical contractors	$905,134	$282,556	$768,145	$892,178	$1,955,836	$2,079,868
2354	Masonry, drywall, insulation, tile contractors	$50,072,603	$49,333,693	$67,155,494	$78,428,358	$166,561,790	$177,834,654
2355	Carpentry & floor contractors	$2,200,886	$754,002	$2,622,517	$3,146,308	$5,577,405	$6,101,196
2356	Roofing, siding, & sheet metal contractors	$461,064	$221,674	$432,401	$504,560	$1,115,139	$1,187,298
2357	Concrete contractors	$27,325,904	$24,451,543	$34,870,390	$40,942,578	$86,647,837	$92,720,024
2358	Water well drilling contractors	$4,354,509	$1,643,750	$3,115,830	$3,534,238	$9,114,089	$9,532,497
2359	Other special trade contractors [a]	$16,941,739	$5,519,019	$21,956,099	$25,001,165	$44,416,857	$47,461,923
	Total	$176,743,869	$120,352,401	$224,751,887	$260,660,244	$521,848,157	$557,756,514

[a] Includes program costs for abrasive blasters.

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SECTION FIVE

ECONOMIC IMPACTS

This section presents the economic impacts of OSHA's prospective silica rule on construction establishments. Compliance costs per establishment are described in Section 5.1, followed by a discussion of establishment-level impacts on revenues and profits in Section 5.2. Section 5.3 presents impacts on small entities. Market mechanisms that underlie industry-level impacts are provided in Section 5.4. Finally, Sections 5.5 and 5.6 examine and illustrate the nature and potential size of these industry-level impacts using cost data from Section 4.

5.1 COMPLIANCE COSTS PER ESTABLISHMENT

Table 5-1 presents compliance costs per establishment for the 50, 75, and 100 $\mu g/m^3$ PELs. The costs per establishment were calculated by distributing the industry-level incremental control costs, costs for respirators, and most expensive program costs from Section 4 among all establishments.[1] (Data do not allow estimation of the number of establishments in each industry that are engaged in silica-exposure-generating activity.)

The weighted average cost per establishment across all industries is $961, $935, and $786 for the 50, 75, and 100 $\mu g/m^3$ PELs, respectively. As shown in Table 5-1, projected per-establishment costs range from $4,780 for the highway construction industry to $38 for land subdivision and land development. The cost for highway construction establishments is relatively high due to the large amount of heavy equipment operation, rock drilling, concrete drilling, and material handling in street, bridge and tunnel construction projects. In addition to the size of total industry costs, the magnitude of per-establishment costs are also influenced by the relative number of establishments in an industry. While masonry, drywall, insulation, and tile contractors incurred the highest total industry control costs (Table 4-14, 4-16, and 4-18), the

[1] Estimates were based from US Census 2000 County Business Patterns four-digit level NAICS establishment totals (U.S. Bureau of the Census, 2001a).

Table 5-1

Compliance Costs per Establishment: PEL = 50 Micrograms per Cubic Meter
($)

NAICS	Title	Option: PEL = 50 Micrograms per Cubic Meter	Option: PEL = 75 Micrograms per Cubic Meter	Option: PEL = 100 Micrograms per Cubic Meter
2331	Land subdivision & land development	$37.68	$35.22	$29.39
2332	Residential building construction	$244.93	$221.00	$187.40
2333	Nonresidential building construction	$2,167.35	$2,129.18	$1,803.39
2341	Highway, street, bridge & tunnel construction	$4,779.33	$4,679.89	$3,851.00
2349	Other heavy construction	$2,206.52	$2,069.78	$1,708.16
2351	Plumbing, heating & AC contractors	$57.37	$54.21	$45.73
2352	Painting & wall covering contractors	$369.15	$367.51	$362.32
2353	Electrical contractors	$39.19	$36.84	$31.13
2354	Masonry, drywall, insulation, tile contractors	$3,960.23	$3,968.97	$3,316.26
2355	Carpentry & floor contractors	$151.13	$122.77	$104.25
2356	Roofing, siding, & sheet metal contractors	$49.47	$43.56	$38.34
2357	Concrete contractors	$3,723.94	$3,676.52	$3,066.34
2358	Water well drilling contractors	$3,402.93	$2,955.33	$2,510.53
2359	Other special trade contractors	$756.33	$717.01	$606.10
Average across industries		$961	$935	$786

Source: Calculated by dividing total compliance costs by the number of establishments in each industry.

highest respirator costs (Table 4-24), and the highest program costs (Table 4-45), these costs are distributed over a large number of establishments.

5.2 ECONOMIC IMPACTS PER ESTABLISHMENT

Table 5-2 presents incremental compliance costs as a percentage of revenues and profits for construction establishments. ERG estimated revenues on a four-digit NAICS basis using data from the Census Bureau's Statistics of U.S. Businesses for 1997 and 2000 (U.S. Bureau of the Census, 2001b). Because revenue data are only available for 1997, ERG used the ratio of annual payroll amounts in 1997 and 2000 to extrapolate revenues in the year 2000.

ERG collected pre-tax profit rate data from Risk Management Association's (RMA) Annual Statement Studies 2000-2001 publication, which contains income statement data on a four-digit SIC level (RMA, 2001). To get profit rates on a four-digit NAICS basis, ERG needed to first match four-digit NAICS codes with three-digit SIC codes. ERG then calculated the average profit rate at the three-digit SIC level using the available profit rate data at the four-digit SIC level.[2] The profit rates shown in the table are the average of before-tax profit rates for 2000, 1999, and 1998. Before-tax profits per establishment are estimated by applying the before-tax profit rates to the extrapolated revenue statistics.

As shown, the largest impact on revenues is incurred by water well drilling contractors (NAICS 2358). This industry has relatively high per-establishment compliance costs and relatively small revenues. For NAICS 2358, compliance costs comprise 0.49 percent of revenues for the 50 $\mu g/m^3$ PEL, 0.43 percent for the 75 $\mu g/m^3$ PEL, and 0.36 percent for the 100 $\mu g/m^3$ PEL. The average percent of compliance costs to revenues for all industries is 0.11 percent for the 50 and 75 $\mu g/m^3$ PELs, and 0.09 percent for the 100 $\mu g/m^3$ PEL.

[2] RMA's Annual Statement Studies did not publish profit rate data for water well drilling contractors (SIC 1781/NAICS 2358) or for the corresponding three-digit SIC. As a proxy, ERG used the average before-tax profit rate for all available SIC codes under two-digit SIC 17.

Table 5-2

Economic Impacts, Construction Industry
($)

NAICS	Title	Number of Establishments [a]	Revenues ($1,000) [b]	Revenues per Establishment	Profit Rate [c]	Profits per Establishment
2331	Land subdivision & land development	13,111	$24,987,756	$1,905,862	3.8%	$72,423
2332	Residential building construction	159,550	$197,215,877	$1,236,076	3.5%	$43,675
2333	Nonresidential building construction	43,693	$265,917,346	$6,086,040	2.7%	$162,294
2341	Highway, street, bridge & tunnel construction	11,795	$73,991,374	$6,273,113	3.9%	$244,651
2349	Other heavy construction	27,721	$95,740,759	$3,453,727	4.3%	$147,743
2351	Plumbing, heating & AC contractors	90,487	$114,663,692	$1,267,184	3.1%	$39,283
2352	Painting & wall covering contractors	40,973	$17,712,628	$432,300	3.5%	$15,130
2353	Electrical contractors	66,802	$98,434,889	$1,473,532	3.4%	$50,591
2354	Masonry, drywall, insulation, tile contractors	53,625	$53,670,115	$1,000,841	4.2%	$41,869
2355	Carpentry & floor contractors	58,525	$39,783,119	$679,763	3.7%	$25,378
2356	Roofing, siding, & sheet metal contractors	30,966	$29,673,365	$958,256	2.8%	$27,151
2357	Concrete contractors	30,238	$35,484,678	$1,173,513	4.1%	$48,114
2358	Water well drilling contractors	3,797	$2,617,263	$689,298	3.9%	$26,898
2359	Other special trade contractors	78,307	$80,523,351	$1,028,303	4.3%	$44,103

	Option: PEL = 50 Micrograms per Cubic Meter			Option: PEL = 75 Micrograms per Cubic Meter			Option: PEL = 100 Micrograms per Cubic Meter		
NAICS	Compliance Costs per Establishment	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits	Compliance Costs per Establishment	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits	Compliance Costs per Establishment	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits
2331	$37.68	0.00%	0.05%	$35.22	0.00%	0.05%	$29.39	0.00%	0.04%
2332	$244.93	0.02%	0.56%	$221.00	0.02%	0.51%	$187.40	0.02%	0.43%
2333	$2,167.35	0.04%	1.34%	$2,129.18	0.03%	1.31%	$1,803.39	0.03%	1.11%
2341	$4,779.33	0.08%	1.95%	$4,679.89	0.07%	1.91%	$3,851.00	0.06%	1.57%
2349	$2,206.52	0.06%	1.49%	$2,069.78	0.06%	1.40%	$1,708.16	0.05%	1.16%
2351	$57.37	0.00%	0.15%	$54.21	0.00%	0.14%	$45.73	0.00%	0.12%
2352	$369.15	0.09%	2.44%	$367.51	0.09%	2.43%	$362.32	0.08%	2.39%
2353	$39.19	0.00%	0.08%	$36.84	0.00%	0.07%	$31.13	0.00%	0.06%
2354	$3,960.23	0.40%	9.46%	$3,968.97	0.40%	9.48%	$3,316.26	0.33%	7.92%
2355	$151.13	0.02%	0.60%	$122.77	0.02%	0.48%	$104.25	0.02%	0.41%
2356	$49.47	0.01%	0.18%	$43.56	0.00%	0.16%	$38.34	0.00%	0.14%
2357	$3,723.94	0.32%	7.74%	$3,676.52	0.31%	7.64%	$3,066.34	0.26%	6.37%
2358	$3,402.93	0.49%	12.65%	$2,955.33	0.43%	10.99%	$2,510.53	0.36%	9.33%
2359	$756.33	0.07%	1.71%	$717.01	0.07%	1.63%	$606.10	0.06%	1.37%
Average	$961	0.11%	2.89%	$935	0.11%	2.73%	$786	0.09%	2.32%

[a] U.S. Bureau of the Census, County Business Patterns, 2000.
[b] Extrapolated from U.S. Bureau of the Census, Statistics of U.S. Businesses, 1997.
[c] RMA, Annual Statement Studies, 2000-2001. Before-tax profits; three-year average for years 1999, 2000, and 2001.

Three industries incur compliance costs greater than five percent of profits for all three PELs. The most severe impacts on profits are incurred by water well drilling contractors at 12.65 percent for the 50 $\mu g/m^3$ PEL. For other construction industries, compliance costs as a percent of profits range from 0.05 percent to 9.46 percent for this PEL option. Average compliance costs across all industries as a percent of profits are 2.89 for the 50 $\mu g/m^3$ PEL, 2.73 for the 75 $\mu g/m^3$ PEL, and 2.32 percent for the 100 $\mu g/m^3$ PEL.

5.3 SMALL BUSINESS IMPACTS

In accordance with the Small Business Regulatory Enforcement Fairness Act (SBREFA), ERG conducted an Initial Regulatory Flexibility Analysis (IRFA) to examine the economic impacts of the proposed silica standard on small entities. ERG estimated and analyzed impacts for entities with fewer than 20 employees, as well as for entities classified as small by the Small Business Administration's (SBA) size standards.

5.3.1 Entities with Fewer than 20 Employees

Table 5-3 presents impacts on entities with fewer than 20 employees for the 50, 75, and 100 $\mu g/m^3$ PELs. ERG extracted the number of entities with fewer than 20 employees from Census's Statistics of U.S. Businesses (U.S. Bureau of the Census, 2001b). This source contains employment, entity, establishment, and payroll data by employment-size category of entities.

To calculate revenues in 2000 for entities with fewer than 20 employees, ERG applied the same methodology used to extrapolate revenues for affected establishments in Section 5.2. ERG computed total revenues for entities with fewer than 20 employees as the product of 1997 revenues and the ratio of annual payroll in 1997 and 2000 for this employment size group (U.S. Bureau of the Census, 2001b). Revenues per entity are then estimated by dividing total revenues by the number of entities with fewer than 20 employees. The profit rates in the table are the same three-year average rates from RMA's Annual Statement Studies as in Section 5.2.

Table 5-3

Small Business Impacts, Entities with Fewer than 20 Employees, Construction Industry
($)

NAICS	Title	Number of Entities with Fewer than 20 Employees [a]	Revenues ($1,000) [b]	Revenues per Entity	Profit Rate [c]	Profits per Entity
2331	Land subdivision & land development	12,127	$15,564,422	$1,283,452	3.8%	$48,771
2332	Residential building construction	153,381	$113,809,342	$742,004	3.5%	$26,217
2333	Nonresidential building construction	35,110	$51,459,823	$1,465,674	2.7%	$39,085
2341	Highway, street, bridge & tunnel construction	8,110	$10,362,336	$1,277,723	3.9%	$49,831
2349	Other heavy construction	21,592	$17,555,311	$813,047	4.3%	$34,780
2351	Plumbing, heating & AC contractors	80,428	$41,882,385	$520,744	3.1%	$16,143
2352	Painting & wall covering contractors	38,883	$10,762,789	$276,799	3.5%	$9,688
2353	Electrical contractors	57,878	$28,529,692	$492,928	3.4%	$16,924
2354	Masonry, drywall, insulation, tile contractors	47,230	$19,782,406	$418,853	4.2%	$17,522
2355	Carpentry & floor contractors	55,323	$21,292,857	$384,883	3.7%	$14,369
2356	Roofing, siding, & sheet metal contractors	27,835	$13,216,106	$474,802	2.8%	$13,453
2357	Concrete contractors	27,062	$14,796,070	$546,747	4.1%	$22,417
2358	Water well drilling contractors	3,577	$1,804,117	$504,366	3.9%	$19,681
2359	Other special trade contractors	70,629	$35,215,286	$498,595	4.3%	$21,384

	Option: PEL = 50 Micrograms per Cubic Meter			Option: PEL = 75 Micrograms per Cubic Meter			Option: PEL = 100 Micrograms per Cubic Meter		
NAICS	Compliance Costs per Small Entity	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits	Compliance Costs per Small Entity	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits	Compliance Costs per Small Entity	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits
2331	$24.20	0.00%	0.05%	$22.62	0.00%	0.05%	$18.88	0.00%	0.04%
2332	$193.72	0.03%	0.74%	$174.79	0.02%	0.67%	$148.22	0.02%	0.57%
2333	$745.24	0.05%	1.91%	$732.12	0.05%	1.87%	$620.09	0.04%	1.59%
2341	$1,202.98	0.09%	2.41%	$1,177.95	0.09%	2.36%	$969.31	0.08%	1.95%
2349	$602.18	0.07%	1.73%	$564.86	0.07%	1.62%	$466.17	0.06%	1.34%
2351	$29.46	0.01%	0.18%	$27.84	0.01%	0.17%	$23.48	0.00%	0.15%
2352	$282.97	0.10%	2.92%	$281.71	0.10%	2.91%	$277.74	0.10%	2.87%
2353	$16.62	0.00%	0.10%	$15.62	0.00%	0.09%	$13.21	0.00%	0.08%
2354	$1,850.76	0.44%	10.56%	$1,854.85	0.44%	10.59%	$1,549.81	0.37%	8.84%
2355	$100.68	0.03%	0.70%	$81.78	0.02%	0.57%	$69.45	0.02%	0.48%
2356	$28.20	0.01%	0.21%	$24.83	0.01%	0.18%	$21.86	0.00%	0.16%
2357	$2,100.85	0.38%	9.37%	$2,074.10	0.38%	9.25%	$1,729.87	0.32%	7.72%
2358	$2,724.65	0.54%	13.84%	$2,366.27	0.47%	12.02%	$2,010.13	0.40%	10.21%
2359	$450.58	0.09%	2.11%	$427.15	0.09%	2.00%	$361.08	0.07%	1.69%
Average	$447	0.13%	3.35%	$432	0.13%	3.17%	$365	0.11%	2.69%

[a] U.S. Bureau of the Census, Statistics of U.S. Businesses, 2000.
[b] Extrapolated from U.S. Bureau of the Census, Statistics of U.S. Businesses, 1997.
[c] RMA, Annual Statement Studies, 2000-2001. Before-tax profits; three-year average for years 1999, 2000, and 2001.

Compliance costs for entities with fewer than 20 employees were estimated using a derived compliance cost per employee figure. Assuming costs to be equally distributed among all employees, ERG estimated the compliance cost per employee by dividing total costs for each NAICS by the number of employees. ERG then multiplied the compliance cost per employee with the ratio of the average number of employees per entity with fewer than 20 employees. For example, there are slightly fewer than 4 employees per entity for this class of very small entities in the residential building construction industry. The compliance cost per employee is approximately $50 for the 50 $\mu g/m^3$ PEL. Using the methodology explained above, ERG calculated compliance costs at $194 per very small entity for this construction industry.

The weighted average compliance costs per very small entity are $447 for the 50 $\mu g/m^3$ PEL, $432 for the 75 $\mu g/m^3$ PEL, and $365 for the 100 $\mu g/m^3$ PEL. Water well drilling contractors incur the largest costs at $2,725 per very small entity. Across industries, on average these costs comprise 0.13 percent of revenues at the 50 and 75 $\mu g/m^3$ PELs, and 0.11 percent of revenues at the 100 $\mu g/m^3$ PEL (see Table 5-3). The most severe impact is incurred by water well drilling contractors (NAICS 2358). For this industry, compliance costs comprise 0.54 percent of revenues for the 50 $\mu g/m^3$ PEL.

Compliance costs range from 0.05 to 13.84 percent of profits for entities with fewer than 20 employees. For three industries, costs are greater than five percent of profits for all three PELs. One construction industry incurs costs greater than ten percent of profits for all three PELs. Water well drilling contractors experience the largest impacts on profits. The average impact on profits for this size class across all construction industries is 3.35 percent for the 50 $\mu g/m^3$ PEL, 3.17 percent for the 75 $\mu g/m^3$ PEL, and 2.69 percent for the 100 $\mu g/m^3$ PEL.

5.3.2 Entities Classified as Small by SBA

SBA size standards for the construction industry are expressed in terms of revenues (U.S. SBA, 2002). For instance, entities in NAICS 2331 (land subdivision and land development) are classified as small if their annual revenues are less than $6 million. To find the number of entities classified as small for each industry, ERG first extrapolated average revenues per entity for all employment size groups using size-category-specific 1997 revenue data and the 1997 to 2000 annual payroll ratio (U.S. Bureau of the Census, 2001b). ERG then located the largest employment size category with revenues less than the SBA revenue size standard for each NAICS.

Total revenues for small entities are calculated as the sum of revenues for all size groups below the maximum SBA revenue classification. Total revenues are divided by the total number of entities within the SBA size classification to derive revenues per SBA-defined small entity. Compliance costs per small entity are estimated from the product of compliance costs per employee (as calculated in Section 5.3.1) and the average number of employees in entities within the SBA classification.

Table 5-4 shows small business impacts for entities classified as small by SBA size standards. The weighted average compliance cost per small entity is \$802, \$779, \$656 for the 50, 75, and 100 $\mu g/m^3$ PELs, respectively. The largest costs per SBA-defined small entity are incurred by water well drilling contractors. Costs amount to \$3,544 per small entity for this industry. The most severe impacts on revenues are also incurred by the same industry at 0.55 percent. On average, costs are 0.13 percent of revenues for the 50 and 75 $\mu g/m^3$ PELs and 0.11 percent of revenues for the 100 $\mu g/m^3$ PEL.

Compliance costs as a percent of profits average 3.38 percent for the 50 $\mu g/m^3$ PEL, 3.20 percent for the 75 $\mu g/m^3$ PEL, and 2.72 percent for the 100 $\mu g/m^3$ PEL for SBA-defined small entities. For three industries, costs exceed five percent of profits for all three PELs. Costs exceed ten percent of profits for one industry for the 50, 75, and 100 $\mu g/m^3$ PELs. The most severely impacted industry is water well drilling contractors for whom costs are almost 14 percent of profits.

5.3.3 Summary

The economic data provide limited means to differentiate impacts among large and small businesses. The distribution of impacts is affected by the characteristics of the compliance measures. For silica controls in construction, the dust control measures consist primarily of equipment modifications and additions made to individual tools, rather than large, discrete investments, such as might be applied in a manufacturing setting. As a result, compliance advantages for large firms through economies of scale are

Table 5-4

Small Business Impacts, Entities Classified as Small by SBA, Construction Industry
($)

NAICS	Title	SBA Small Business Classification Revenues Limit ($1,000) [a]	Number of Entities with Classified as Small by SBA [b]	Revenues ($1,000) [c]	Revenues per Entity	Profit Rate [d]	Profits per Entity
2331	Land subdivision & land development	$6,000	12,127	$15,564,422	$1,283,452	3.8%	$48,771
2332	Residential building construction	$28,500	158,388	$152,672,235	$963,913	3.5%	$34,058
2333	Nonresidential building construction	$28,500	41,796	$138,698,711	$3,318,469	2.7%	$88,492
2341	Highway, street, bridge & tunnel construction	$28,500	10,601	$33,005,011	$3,113,387	3.9%	$121,422
2349	Other heavy construction	$28,500	26,854	$66,533,826	$2,477,613	4.3%	$105,987
2351	Plumbing, heating & AC contractors	$12,000	88,648	$79,832,729	$900,559	3.1%	$27,917
2352	Painting & wall covering contractors	$12,000	40,797	$15,827,931	$387,968	3.5%	$13,579
2353	Electrical contractors	$12,000	64,829	$58,207,890	$897,868	3.4%	$30,827
2354	Masonry, drywall, insulation, tile contractors	$12,000	52,452	$37,828,085	$721,194	4.2%	$30,170
2355	Carpentry & floor contractors	$12,000	57,907	$31,637,435	$546,349	3.7%	$20,397
2356	Roofing, siding, & sheet metal contractors	$12,000	30,575	$24,231,194	$792,517	2.8%	$22,455
2357	Concrete contractors	$12,000	29,800	$26,562,826	$891,370	4.1%	$36,546
2358	Water well drilling contractors	$12,000	3,732	$2,424,138	$649,555	3.9%	$25,347
2359	Other special trade contractors	$12,000	76,323	$59,515,074	$779,779	4.3%	$33,444

	Option: PEL = 50 Micrograms per Cubic Meter			Option: PEL = 75 Micrograms per Cubic Meter			Option: PEL = 100 Micrograms per Cubic Meter		
NAICS	Compliance Costs per Small Entity	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits	Compliance Costs per Small Entity	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits	Compliance Costs per Small Entity	Compliance Costs as a % of Revenues	Compliance Costs as a % of Profits
2331	$24.20	0.00%	0.05%	$22.62	0.00%	0.05%	$18.88	0.00%	0.04%
2332	$251.18	0.03%	0.74%	$226.63	0.02%	0.67%	$192.18	0.02%	0.56%
2333	$1,496.90	0.05%	1.69%	$1,470.54	0.04%	1.66%	$1,245.52	0.04%	1.41%
2341	$2,926.74	0.09%	2.41%	$2,865.84	0.09%	2.36%	$2,358.26	0.08%	1.94%
2349	$1,725.47	0.07%	1.63%	$1,618.54	0.07%	1.53%	$1,335.76	0.05%	1.26%
2351	$48.34	0.01%	0.17%	$45.68	0.01%	0.16%	$38.54	0.00%	0.14%
2352	$406.46	0.10%	2.99%	$404.65	0.10%	2.98%	$398.95	0.10%	2.94%
2353	$29.23	0.00%	0.09%	$27.48	0.00%	0.09%	$23.23	0.00%	0.08%
2354	$3,323.99	0.46%	11.02%	$3,331.32	0.46%	11.04%	$2,783.48	0.39%	9.23%
2355	$143.38	0.03%	0.70%	$116.48	0.02%	0.57%	$98.91	0.02%	0.48%
2356	$48.38	0.01%	0.22%	$42.61	0.01%	0.19%	$37.50	0.00%	0.17%
2357	$3,453.92	0.39%	9.45%	$3,409.94	0.38%	9.33%	$2,844.01	0.32%	7.78%
2358	$3,544.15	0.55%	13.98%	$3,077.98	0.47%	12.14%	$2,614.72	0.40%	10.32%
2359	$713.85	0.09%	2.13%	$676.74	0.09%	2.02%	$572.06	0.07%	1.71%
Average	$802	0.13%	3.38%	$779	0.13%	3.20%	$656	0.11%	2.72%

[a] U.S. Small Business Administration, Table of Small Business Size Standards, 2002.
[b] U.S. Bureau of the Census, Statistics of U.S. Businesses, 2000.
[c] Extrapolated from U.S. Bureau of the Census, Statistics of U.S. Businesses, 1997.
[d] RMA, Annual Statement Studies, 2000-2001. Before-tax profits; three-year average for years 1999, 2000, and 2001.

limited. Some large construction firms might have additional purchasing power for buying dust control measures in bulk. Given the simplicity of many control measures, however, such as the use of wet methods on machines already manufactured to accommodate them, such differential purchasing power appears to be of limited consequence.

The greater capital resources of large firms will give them some advantage in making the relatively large investments for some control measures. For example, cab enclosures on heavy construction equipment or foam-based dust control systems on rock crushers might be particularly expensive for some small entities with an unusual number of heavy equipment pieces. Nevertheless, where differential investment capabilities might exist, small construction firms might also have the capability to achieve compliance with lower-cost measures, such as by modifying work practices. In the case of rock crushing, for example, simple water spray systems can be arranged without large-scale investments in the best commercially available systems.

In the program area, large firms might have a slight advantage in the delivery of training or in arranging for health screenings. Given the likelihood that small firms can call upon independent training specialists at competitive prices, and the widespread availability of medical services for health screenings, the advantage for large firms is, again, extremely modest.

5.4 MARKET STRUCTURE AND IMPACTS

Compliance costs increase the cost of construction projects that generate silica exposures. Consequently, a rise in the cost of construction projects could have a significant impact on industry supply and demand.

The market-determined output of the construction industry depends on the equilibrium of demand and supply. Incremental compliance costs shift the construction supply curve upward. Depending on the demand elasticity, the net result is an increase in the price for construction outputs (e.g., new buildings) and a reduction in the output level. Lower levels of output mean less construction work, a reduction in the number of construction establishments, and a concomitant reduction in construction employment. The greater the price elasticity, the larger will be the reduction in equilibrium output. The magnitude of this impact depends on the supply and as well as the demand relationship. The greater the increment to marginal costs, the larger the reduction in equilibrium output for any given demand elasticity. In terms of prices, the larger the demand elasticity, the smaller will be the increase in prices for a given increment to marginal costs, but the larger the reduction in output.

Increasing the cost of construction project activities that generate silica exposures has two effects on the demand for these activities. First, increasing the cost of silica-related jobs relative to the costs of other construction inputs might result in substitution away from this type of work. Architects, building designers, and contractors might be more likely to choose building methods and materials that eliminate or reduce the need to perform the silica related jobs. For example, pre-cast concrete structures that require a relatively high level of concrete finishing work would become more expensive relative to other building technologies. Contractors and others would reduce the cost impact of the standard by switching to other unaffected building methods. The extent to which such impacts are likely will depend on the feasibility, attributes, and relative expense of alternative technologies.

Second, an increase in the cost of silica-generating activities, depending on the extent of substitution, will increase the marginal cost of construction output and cause the construction supply curve to shift upward. As argued above, depending on the construction demand relationship, this shift in the supply curve will result in a higher price and a lower level of construction output. The magnitude of the impact of the regulation-induced cost increases on the supply relationship will depend on the size of the cost increases any the importance of silica-generating activities in the overall cost of construction projects. Table 5-5 displays construction payrolls as a percent of the net value of construction work. As shown, labor costs represent, overall, about 20 percent of the value of construction output. In the absence of compensating adjustments and holding output constant, a 10 percent increase in labor costs, therefore, is expected to generate a 2 percent increase in the value of construction investment.

Table 5-5

Net Value of Construction Work, by Industry, 1997
($thousands)

NAICS/Industry	Net Value of Construction Work	Payroll for Construction Workers	Labor Share of Value
233 Building, developing, and general contracting	$198,826,896	$23,135,832	11.6%
2331 Land subdivision and development	$10,247,820	$254,247	2.5%
2332 Residential building construction	$100,124,176	$8,762,122	8.8%
2333 Nonresidential building construction	$88,454,896	$14,119,462	16.0%
234 Heavy construction	$105,639,352	$22,218,582	21.0%
2341 Highway, street, bridge, & tunnel construction	$46,274,084	$8,473,898	18.3%
2349 Other heavy construction	$59,365,264	$13,744,685	23.2%
235 Special trade contractors	$307,742,752	$74,322,376	24.2%
2345 Masonry, drywall, insulation, & tile contactors	$34,843,408	$10,072,856	28.9%
2357 Concrete contractors	$23,603,728	$5,298,498	22.4%
-- All other special trade contractors	$249,295,616	$58,951,022	23.6%
All construction	$612,209,024	$119,676,792	19.5%

Source: U.S. Bureau of the Census, 1997 Economic Census: Construction Industry Summary. January, 2000.

5.5 MARKET IMPACTS ON CONSTRUCTION INVESTMENT

Table 5-6 shows, by industry, the estimated value of silica-generating activities affected by the proposed silica rule.[3] Overall, these projects represent an estimated 6.4 percent of net construction investment (adjusted for inflation), or $40.1 billion. As shown, the share of net investment accounted for by these projects is the highest for highway construction, other heavy construction, masonry contractors, and concrete contractors (16.5, 16.4, 14.3, and 12.0 percent of net investment, respectively), and lowest for land subdivision and land development contractors (less than 1.0 percent). These statistics suggest, other things equal and holding demand constant, that a 10 percent regulation-induced cost increase in silica-related projects might generate an overall increase in the value of construction investment on the order of 0.64 percent, with increases in the value of investments produced by heavy construction contractors and high-impact masonry contractors on the order of 1.7 to 1.5 percent.[4]

Table 5-6 shows the estimates of the regulatory costs imposed by the regulation. These costs include both control and program costs for the most expensive of the PEL options. Overall, ERG estimates incremental compliance costs at 1.7 percent of the value of affected, silica-generating activities, or $0.7 billion. However, while the cost of affected projects might rise by 1.7 percent, this cost increase as a percent of total construction investment is only 0.11 percent. In two construction industries, compliance costs as a percent of net investment rise are close to 0.5 percent. The relative cost impacts for masonry and concrete contractors are estimated at 0.60 and 0.47 percent of net investment, respectively. The final column shows compliance costs as a percent of construction labor costs. The cost impacts relative to labor costs are 2.1 percent or less for all industries, including the two high-impact industries.

[3] See Section 4 for a presentation of the methodology used to estimate the value of construction projects where silica dust control measures will be required by the regulation.

[4] These calculations are the equivalent of assuming a zero demand elasticity.

Table 5-6

Aggregate Impacts on the Construction Industry from OSHA's Silica Rule
($1,000s)

NAICS/Industry	Net Value of Construction Work [a]	Estimated Value of Silica-Generating Activities		Total Compliance Costs[c]	Percent of Silica-Generating Activities	Percent of Net Construction Investment	Percent of Construction Labor Costs
		Total [b]	Percent of Net Construction Investment				
233 Building, developing, and general contracting	$202,743,786	$4,936,330	2.4%	$134,271	2.7%	0.066%	0.580%
2331 Land subdivision and development	$10,449,702	$74,526	0.7%	$494	0.7%	0.005%	0.194%
2332 Residential building construction	$102,096,622	$1,713,828	1.7%	$39,079	2.3%	0.038%	0.446%
2333 Nonresidential building construction	$90,197,457	$3,147,976	3.5%	$94,698	3.0%	0.105%	0.671%
234 Heavy construction	$107,720,447	$17,738,031	16.5%	$117,539	0.7%	0.109%	0.529%
2341 Highway, street, bridge, & tunnel construction	$47,185,683	$7,806,928	16.5%	$56,372	0.7%	0.119%	0.665%
2349 Other heavy construction	$60,534,760	$9,931,103	16.4%	$61,167	0.6%	0.101%	0.445%
235 Special trade contractors	$313,805,284	$17,474,097	5.6%	$430,430	2.5%	0.137%	0.579%
2345 Masonry, drywall, insulation, & tile contactors	$35,529,823	$5,077,921	14.3%	$212,367	4.2%	0.598%	2.108%
2357 Concrete contractors	$24,068,721	$2,900,104	12.0%	$112,604	3.9%	0.468%	2.125%
– All other special trade contractors	$254,206,740	$9,496,072	3.7%	$105,458	1.1%	0.041%	0.179%
All construction	$624,269,542	$40,148,458	6.4%	$682,240	1.7%	0.109%	0.570%

[a] 1997 value of construction investment, inflated to 2000 dollars using Bureau of the Census implicit price deflator for construction.
[b] See Table 4-11.
[c] Compliance costs for controls and most expensive combination of program requirements.
Source: ERG estimates and U.S. Bureau of the Census, 1997 Economic Census: Construction Industry Summary. January, 2000.

5.6.2 Nonresidential Building Construction

Nonresidential building construction comprises industrial, commercial, and other nonresidential structures. As such, demand is derived from that demand for the output of the industries in which the buildings are used. For example, the demand for commercial office space is derived from the demand for the output and services produced for the office users. The price elasticity of demand for this construction category will depend on the price elasticity of demand for the final service and the importance of the costs of construction in the total cost of the final service or product. ERG found no studies that attempted to quantify these relationships. But, the resultant price elasticity is likely to be small, certainly less than the elasticity of demand for residential building. Thus dust control requirements in a silica regulation are forecast to have a limited impact on output levels for nonresidential building construction.

5.6.3 Nonbuilding Construction

Nonbuilding construction includes roads, bridges, and other infrastructure projects. Utility construction (powerlines, sewers, water mains, etc.) and a variety of other construction types are also included. A large share of this construction (63.8 percent) is publicly financed. For this reason, decisions regarding the appropriate level of such investments are not made in a private market setting. The relationship between the price (cost) of such investments and the level of demand might depend more on political considerations than the factors that determine the demand for privately produced goods and services. While a number of studies have examined the factors that determine the demand for publicly financed construction projects, these have focused the ability to finance such projects (e.g., tax receipts) and socio-demographic factors (e.g., population growth) to the exclusion of cost or price factors. In the absence of budgetary constraints, ERG believes, therefore, that the price elasticity of demand for public investment is probably quite low. On the other hand, budget-imposed limits might constraint public construction spending. If the dollar value of public investments were fixed, a demand elasticity of -1 would be implied. Any percentage increase in construction costs would be offset with an equal percentage reduction in investment (measured in physical units), keeping public construction expenditures constant.

Public utility construction comprises the remainder of nonbuilding construction. This type of construction is subject to the same derived demand considerations discussed for nonresidential building construction, and for the same reasons, ERG expects the price elasticity to be quite low.

5.7 REFERENCES

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SECTION SIX
BENEFITS

The two primary health effects of silica exposure are silicosis and lung cancer, both of which can result in death. The benefits of the draft silica standard for construction will be the reduction in the number of silicosis and silica-related lung cancer cases due to reduction in exposure levels under the standard. ERG assumes implicitly throughout that at-risk workers that suffer from silica-related health effects either die from silicosis or from lung cancer.

This section provides ERG's estimates of these benefits for three options:

- Option 1—a permissible exposure limit (PEL) of 50 $\mu g/m^3$.
- Option 2—a PEL of 75 $\mu g/m^3$.
- Option 3—a PEL of 100 $\mu g/m^3$.

The section begins by discussing the methods ERG uses in calculating these benefits (Section 5.1). Next, the inputs into the benefit estimates (e.g., number of exposed workers, etc) are discussed. Finally, the estimated benefits are discussed.

6.1 METHOD FOR ESTIMATING THE REDUCED RISK OF SILICA EXPOSURE

6.1.1 General Method

The reduced risk of silicosis and silica-related lung cancer are based on lifetime risk models for each disease. For both silicosis and lung cancer, the reduced number of cases is calculated by multiplying the number of exposed workers by the reduced lifetime risk associated with reducing exposure under the draft silica standard. This can be written as:

$$AC = N \times [R^b - R^p],$$

where AC is the number of avoided cases, N is the number of exposed workers, R^b is baseline lifetime risk, and R^p is post-rule lifetime risk. An estimate of the number of avoided cases is made for four different exposure groupings:

- Workers exposed at more than 40 $\mu g/m^3$, but less then 50 $\mu g/m^3$;
- Workers exposed at more than 50 $\mu g/m^3$, but less than 75 $\mu g/m^3$;
- Workers exposed at more than 75 $\mu g/m^3$, but less than 100 $\mu g/m^3$; and
- Workers exposed at more than 100 $\mu g/m^3$.

Each group has an estimated number of exposed workers and will have different reductions in lifetime risk with reduced exposures under the draft silica standard. The lifetime risk estimates (R^b and R^p) are derived from published epidemiological studies, which we discuss in subsections 5.1.3 and 5.1.4.

Using the equation for avoided cases above will result in an estimate of the reduced number of cases among the N workers. The resulting estimate, however, is not an annual number of cases. Rather, the estimates reflect the reduced number of cases among a cohort of N workers that work in the exposed occupations for 45 years. The model provides no indication of the timing of the avoided cases and thus ERG uses some assumptions in Section 5.2 to derive an annual number of cases.

6.1.2 Assumptions

In calculating lifetime risk, we assume that exposed workers will be employed in silica-exposed occupations for their entire work lives (i.e., from age 20 to age 65). Furthermore, we assume that workers remain in the same exposure group during their work life in the absence of the silica standard.

These assumptions are an important part of the analysis and have implications for the estimated reductions in silica-related risk. First, the assumption that workers will be employed in silica-exposed occupations for their entire working lives implies risk is over-estimated to some degree. In all likelihood, however, few workers will be exposed for 45 years. Thus the 45-years assumption overestimates risk.

A second implication of the 45-year exposure assumption is that no new or "replacement" workers are exposed, thus reducing the pool of at-risk workers that receive benefits from the rule. That is, if workers are assumed to work for 45 years in the occupations, then no replacement workers are hired. In reality, workers will move in and out of silica-exposed occupations. This analysis does not account for such movements, implying a smaller pool of workers that incur risk and thus receive benefits under the draft standard.

The estimates that we generate in this analysis should be considered a "steady state" or "equilibrium" level of avoided risk. In the short-term, the reduced number of cases will be less than the numbers that are estimated here since not all workers will enjoy the reduced exposure level for 45 years. That is, those workers aged 45 at the time the rule takes effect, and that would remain working in the exposed occupation until age 65, would receive only 20 years of reduced exposure. The estimates generated here assume that workers would receive 45 years of the baseline exposure level under the baseline scenario and would receive 45 years of the post-rule exposure level under the post-rule scenarios. Thus, no adjustment is made for the age distribution or work histories of current workers. In a world where workers are employed for 45 years in the exposed occupations, the numbers estimated here would eventually be the "equilibrium" levels of cases.

6.1.3 Lifetime Silicosis Risk

The lifetime risk of silicosis is derived from Steenlund et al (2002). In that study, the risk of silicosis is derived silicosis-related mortality rates. Lifetime risk is calculated as

$$Risk = 1 - exp\left[- \sum t \cdot MR(e)\right]$$

where $MR(e)$ is a mortality rate associated with a level of cumulative exposure (e) and t is the time spent *at that mortality rate*. The relationship between mortality rates and cumulative exposure is given in Table 6-1.

Table 6-1. Silicosis Mortality Rates	
Cumulative Exposure (μg/m³)	**Mortality Rate per 100,000 person-years**
0 – 990	4.7
990 – 1,970	15.9
1,970 – 2,870	29.2
2,870 – 4,330	44.2
4,330 – 7,120	64.3
7,120 – 9,580	106.4
9,580 – 13,210	112.6
13,210 – 15,890	189.2
15,890 – 28,100	118.0
> 28,100	299.1
Source: Steenlund et al., 2002.	

Calculating lifetime risk in this framework requires tracking the cumulative exposure of exposed individuals. For example, consider a worker exposed at 40 μg/m³ for each workday of each year from age 20 to age 65. To calculate lifetime risk for this worker, cumulative exposure must be tracked each year of the person's life to determine the time spent at each mortality rate. This hypothetical worker will have cumulative a exposure in the first group (0 – 990 μg/m³) from age 20 to age 44 (25 years), at which point the cumulative exposure exceeds 990 μg/m³ and the worker move to the next category. The worker will then have cumulative exposures in the next category from age 45 to age 65 (21 years). Thus, risk for this worker is calculated as:

$$Risk = 1 - exp[-(25 \cdot 4.7 + 21 \cdot 15.9)] = 0.0045038$$

This can also be expressed as risk per 1,000 workers by multiplying by 1,000. Thus, the risk for workers exposed at 40 μg/m³ is 4.504 per 1,000 workers.

6.1.4 Lifetime Lung Cancer Risk

The lifetime risk of lung cancer is taken from Steenlund et al (2001). In that study, the authors develop a life table for silica-related lung cancer. That analysis is not presented here in order to avoid a lengthy exposition of that method. In brief, they calculate the risk of silica-related lung cancer as the excess risk of lung cancer posed by exposure to silica. That is, each person has some underlying risk of developing lung cancer from non-silica causes. Using data from several cohorts of silica-exposed individuals, they calculate the excess lung cancer risk posed by exposure to silica. Excess risk is influenced by a number of factors, including age, cumulative exposure, and exposure duration. The analysis contained in Steenlund et al (2001) also accounts for the fact that workers could die from other non-lung cancer causes. Thus, the lifetime risk estimates generated using Steenlund et al (2001) reflect the risk of developing silica-related lung cancer after accounting for the risk of developing lung cancer from other causes and after accounting for the possibility that workers could die from other non-lung cancer causes.

6.1.5 Data Used In Calculating Risk

Three data elements are needed to calculate the reduced number of cases of silicosis and lung cancer:

- The number of exposed workers in each exposure group;
- The baseline exposure level for workers in each exposure group; and
- Post-rule exposure levels for each exposure group under each of the scenarios.

Table 6-2 summarizes the data used in this analysis for each of these data elements.

Table 6-2. Data Elements Used in Calculating Reduced Risk

Exposure Group	Number of Exposed Workers [a]	Baseline Exposure Level [b]	Post-Rule Exposure Levels [c]		
			Option 1 (50 $\mu g/m^3$ PEL)	Option 2 (75 $\mu g/m^3$ PEL)	Option 3 (100 $\mu g/m^3$ PEL)
40 – 50 $\mu g/m^3$	19,291	45 $\mu g/m^3$	50 $\mu g/m^3$	75 $\mu g/m^3$	100 $\mu g/m^3$
50 – 75 $\mu g/m^3$	27,379	62.5 $\mu g/m^3$	50 $\mu g/m^3$	75 $\mu g/m^3$	100 $\mu g/m^3$
75 - 100 $\mu g/m^3$	24,944	87.5 $\mu g/m^3$	50 $\mu g/m^3$	75 $\mu g/m^3$	100 $\mu g/m^3$
More than 100 $\mu g/m^3$	100,422	125 $\mu g/m^3$	50 $\mu g/m^3$	75 $\mu g/m^3$	100 $\mu g/m^3$
Totals	**172,036**	-	-	-	-

[a] Source: Section 3, Table 3-2.
[b] Baseline exposures are assumed to be the mid-point of the exposure levels that define each exposure group, except for the more than 100 $\mu g/m^3$. For the more than 100 $\mu g/m^3$ group, ERG assumes that exposures will be 125 $\mu g/m^3$.
[c] The post-rule exposure level is assumed to be the PEL for each option.

6.2 ESTIMATED REDUCTION IN SILICA-RELATED RISK

To estimate the number of avoided silicosis and lung cancer cases, ERG first calculated the number of baseline cases and then calculated the number of post-rule cases. The number of baseline cases was calculated using the baseline exposure levels and the number of workers in Table 6-2, as well as the methods discussed in Section 5.1. The number of post-rule cases was also calculated using the baseline exposure levels and the number of workers in Table 6-2, as well as the methods discussed in Section 5.1. In calculating the post-rule cases, however, three calculations were performed for each exposure group: i.e., one for each option.

This section starts by presenting the number of avoided silicosis cases (Section 5.2.1) and then presents the number of avoided lung cancer cases (Section 5.2.2). A final section translates the estimates from a total number of cases to an annual number of cases. The estimates presented in Sections 5.2.1 and 5.2.2 are the total number of cases among the full workforce in the exposed occupations, assuming that each worker in that workforce is exposed for 45 years.

6.2.1 Avoided Silicosis Cases

The estimated numbers of avoided silicosis cases are presented in Table 6-3. Under Option 1 (50 $\mu g/m^3$ PEL), the draft silica standard will reduce the number of silicosis cases among the at-risk population by 1,181.07 cases. This represents a 54.6 percent reduction in the number of baseline cases for this group of workers. Almost all of the reduction in cases occurs among workers exposed above 100 $\mu g/m^3$. Under this option, benefits are provided to the 152,745 workers with exposures exceeding 50 $\mu g/m^3$.

Under Option 2 (75 $\mu g/m^3$ PEL), the draft silica standard will reduce the number of silicosis cases among the at-risk population by 709.72 cases. This represents a 32.8 percent reduction in the number of baseline cases for this group of workers. Once again, almost all of the reduction in cases occurs among workers exposed above 100 $\mu g/m^3$. Under this option, benefits are provided to the 125,366 workers with exposures exceeding 75 $\mu g/m^3$.

Under Option 3 (100 $\mu g/m^3$ PEL), the draft silica standard will reduce the number of silicosis cases among the at-risk population by 343.44 cases. This represents a 15.9 percent reduction in the number of baseline cases for this group of workers. Given the definition of this PEL, all of the reduction in cases occurs among workers exposed above 100 $\mu g/m^3$. Under this option, benefits are provided to the 100,422 workers with exposures exceeding 75 $\mu g/m^3$.

Table 6-3. Baseline, Post-Rule, and Avoided Silicosis Cases

Category	At-Risk Population	Baseline Number of Cases	Post-Rule Number of Cases	Avoided Cases	
				Number	As a Percentage of Baseline
Option 1 (50 $\mu g/m^3$ PEL)					
40 – 50 $\mu g/m^3$	19,291	89.12	89.12	0.00	0.0%
50 – 75 $\mu g/m^3$	27,379	201.51	160.17	41.34	20.5
75 – 100 $\mu g/m^3$	24,944	272.39	145.92	126.46	46.4%
More than 100 $\mu g/m^3$	100,422	1,600.73	587.47	1,013.26	63.3%
Totals	***172,036***	***2,163.75***	***982.69***	***1,181.07***	***54.6%***
Option 2 (75 $\mu g/m^3$ PEL)					
40 – 50 $\mu g/m^3$	19,291	89.12	89.12	0.00	0.0%
50 – 75 $\mu g/m^3$	27,379	201.51	201.51	0.00	0.0%
75 – 100 $\mu g/m^3$	24,944	272.39	231.48	40.91	15.0%
More than 100 $\mu g/m^3$	100,422	1,600.73	931.92	668.81	41.8%
Totals	***172,036***	***2,163.75***	***1,454.03***	***709.72***	***32.8%***
Option 3 (100 $\mu g/m^3$ PEL)					
40 – 50 $\mu g/m^3$	19,291	89.12	89.12	0.00	0.0%
50 – 75 $\mu g/m^3$	27,379	201.51	201.51	0.00	0.0%
75 – 100 $\mu g/m^3$	24,944	272.39	272.39	0.00	0.0%
More than 100 $\mu g/m^3$	100,422	1,600.73	1,257.29	343.44	21.5%
Totals	***172,036***	***2,163.75***	***1,820.31***	***343.44***	***15.9%***

6.2.2 Avoided Lung Cancer Cases

Table 6-4 repeats the risk analysis for lung cancer. The draft standard eliminates fewer lung cancer cases than silicosis cases. Under Option 1 (50 $\mu g/m^3$ PEL), the draft silica standard will reduce the number of lung cancer cases among the at-risk population by 529.39 cases. This represents an 11.4 percent reduction in the number of baseline cases for this group of workers. Almost all of the reduction in cases occurs among workers exposed above 100 $\mu g/m^3$. Under this option, benefits are provided to the 152,745 workers with exposures exceeding 50 $\mu g/m^3$.

Under Option 2 (75 $\mu g/m^3$ PEL), the draft silica standard will reduce the number of lung cancer cases among the at-risk population by 264.24 cases. This represents a 5.7 percent reduction in the number of baseline cases for this group of workers. Once again, almost all of the reduction in cases occurs among workers exposed above 100 $\mu g/m^3$. Under this option, benefits are provided to the 125,366 workers with exposures exceeding 75 $\mu g/m^3$.

Under Option 3 (100 $\mu g/m^3$ PEL), the draft silica standard will reduce the number of lung cancer cases among the at-risk population by 108.46 cases. This represents a 2.3 percent reduction in the number of baseline cases for this group of workers. Given the definition of this PEL, all of the reduction in cases occurs among workers exposed above 100 $\mu g/m^3$. Under this option, benefits are provided to the 100,422 workers with exposures exceeding 75 $\mu g/m^3$.

Table 6-4. Baseline, Post-Rule, and Avoided Lung Cancer Cases					
Category	At-Risk Population	Baseline Number of Cases	Post-Rule Number of Cases	Avoided Cases	
				Number	As a Percentage of Baseline
Option 1 (50 μg/m³ PEL)					
40 – 50 μg/m³	19,291	451.80	451.80	0.00	0.0%
50 – 75 μg/m³	27,379	682.84	654.64	28.20	4.1%
75 – 100 μg/m³	24,944	661.76	596.41	65.35	9.9%
More than 100 μg/m³	100,422	2,836.93	2,401.1	435.83	15.4%
Totals	***172,036***	***4,633.32***	***4,103.94***	***529.39***	***11.4%***
Option 2 (75 μg/m³ PEL)					
40 – 50 μg/m³	19,291	451.80	451.80	0.00	0.0%
50 – 75 μg/m³	27,379	682.84	682.84	0.00	0.0%
75 – 100 μg/m³	24,944	661.76	643.55	18.21	2.8%
More than 100 μg/m³	100,422	2,836.93	2,590.90	246.03	8.7%
Totals	***172,036***	***4,633.32***	***4,369.08***	***264.24***	***5.7%***
Option 3 (100 μg/m³ PEL)					
40 – 50 μg/m³	19,291	451.80	451.80	0.00	0.0%
50 – 75 μg/m³	27,379	682.84	682.84	0.00	0.0%
75 – 100 μg/m³	24,944	661.76	661.76	0.00	0.0%
More than 100 μg/m³	100,422	2,836.93	2,728.48	108.46	3.8%
Totals	***172,036***	***4,633.32***	***4,524.87***	***108.46***	***2.3%***

6.2.3 Annual Number of Avoided Cases

As noted above, the number of cases presented in Tables 6-3 and 6-4 represent the number of cases among a cohort of workers. To convert these to annual numbers, OSHA makes assumptions on the timing of the cases. First, OSHA assumes that workers would suffer silica-related mortality after they retire at age 65. Second, OSHA assumes that workers would live until age 85. Finally, OSHA assumes that silica-related deaths would be uniformly distributed across the post-retirement years.

Applying these assumptions to the analysis implies that the number of annual cases will be $1/45^{th}$ of the number of cases in Tables 6-3 and 6-4. An example is useful for demonstrating this conclusion.

Consider all workers that die in some year *t*. From our assumptions above, workers that die in year *t* must have retired sometime between years *t-20* and *t-1*. Thus, deaths in year t occur among 20 retirement cohorts, where a retirement cohort would be a set of workers that retire in the same year. Each retirement cohort represents approximately 1/45th of the workforce, and will therefore incur 1/45th of the deaths that occur among the group of workers.[1] OSHA has assumed that deaths among any retirement cohort will be evenly distributed across the 20 years following retirement, implying that 1/20th of the deaths for any given retirement cohort will occur each year (for those 20 years). Thus, multiplying each of these together:

(1/45th of the deaths) × (1/20th of the deaths among a single retirement cohort) × 20 cohorts = 1/45th of the deaths

Table 6-5 presents OSHA's estimates of the number of annual cases by dividing the numbers in Tables 6-3 and 6-4 by 45. The annual number of avoided cases can be summarized as follows:

- Under Option 1 (50 $\mu g/m^3$), the draft silica standard will reduce silicosis incidence by 26.25 cases annually and lung cancer incidence by 11.76 cases annually.

- Under Option 2 (75 $\mu g/m^3$), the draft silica standard will reduce silicosis incidence by 15.77 cases annually and lung cancer incidence by 5.87 cases annually.

- Under Option 3 (100 $\mu g/m^3$), the draft silica standard will reduce silicosis incidence by 7.63 cases annually and lung cancer incidence by 2.41 cases annually.

[1] This may not be true for any given retirement cohort, but will be true for workers of all ages. OSHA has assumed that workers work from age 20 to age 65 in the same job. Thus, over time, the average number of retirees in any given year must be equal to 1/45th the number of workers in the exposed occupations.

Table 6-5. Estimated Annual Number of Cases of Silicosis and Lung Cancer						
Category	**Silicosis Cases**			**Lung Cancer Cases**		
	Baseline	**Post-Rule**	**Avoided**	**Baseline**	**Post-Rule**	**Avoided**
Option 1 (50 μg/m³ PEL)						
40 – 50 μg/m³	1.98	1.98	0.00	10.04	10.04	0.00
50 – 75 μg/m³	4.48	3.56	0.92	15.17	14.55	0.63
75 – 100 μg/m³	6.05	3.24	2.81	14.71	13.25	1.45
More than 100 μg/m³	35.57	13.05	22.52	63.04	53.36	6.69
Totals	***48.08***	***21.84***	***26.25***	***102.96***	***91.20***	***11.76***
Option 2 (75 μg/m³ PEL)						
40 – 50 μg/m³	1.98	1.98	0.00	10.04	10.04	0.00
50 – 75 μg/m³	4.48	4.48	0.00	15.17	15.17	0.00
75 – 100 μg/m³	6.05	5.14	0.91	14.71	14.30	0.40
More than 100 μg/m³	35.57	20.71	14.86	63.04	57.58	5.47
Totals	***48.08***	***32.31***	***15.77***	***102.96***	***97.09***	***5.87***
Option 3 (100 μg/m³ PEL)						
40 – 50 μg/m³	1.98	1.98	0.00	10.04	10.04	0.00
50 – 75 μg/m³	4.48	4.48	0.00	15.17	15.17	0.00
75 – 100 μg/m³	6.05	6.05	0.00	14.71	14.71	0.00
More than 100 μg/m³	35.57	27.94	7.63	63.04	60.63	2.41
Totals	***48.08***	***40.45***	***7.63***	***102.96***	***100.55***	***2.41***

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