The future burden of lung cancer and silicosis from occupational silica exposure in Australia: A preliminary analysis

Report commissioned by the Australian Council of Trade Unions (ACTU)

April 2022

Curtin University

Authorship and Acknowledgements

This study was authored by Dr Renee Carey (Senior Research Fellow, School of Population Health, Curtin University) and Professor Lin Fritschi (John Curtin Distinguished Professor, School of Population Health, Curtin University).

Review and feedback from Deborah Vallance (Senior Policy Officer, ACTU) and Liam O'Brien (Assistant Secretary, ACTU) were provided at key drafting points.

External peer review has been provided by Dr Deborah Glass (Associate Professor, Monash University) and Kate Cole (Director, Cole Health).

For more information, contact:

Renee Carey

Senior Research Fellow

School of Population Health

Curtin University

renee.carey@curtin.edu.au

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Background

Occupational exposure to respirable crystalline silica (RCS) occurs in many workplaces and industries, including construction, mining and quarrying, and manufacturing. Of recent interest is the manufacturing and processing of engineered stone, which has been found to lead to extremely high levels of exposure to RCS. This exposure has been linked to a variety of health effects including silicosis and lung cancer.

Aims

This report aimed to quantify the future burden of lung cancer and silicosis which may arise due to current or recent occupational exposure to RCS. Specifically, we aimed to:

a. estimate how many future lung cancers (over the lifetime of the population) might be caused by current exposure to RCS;
b. extrapolate this to the number of future silicosis cases that may arise;
c. estimate the future number of lung cancer cases that may be avoided under various intervention scenarios; and
d. extrapolate this to the number of future silicosis cases that may be avoided.

Approach

We used a novel method we have developed, the future excess fraction (FEF) approach, to estimate the future number of lung cancer cases arising from occupational RCS exposure. This method, based on the lifetime risk approach, estimates the excess future burden of disease among those exposed to a risk factor (in this case, RCS) in a specific year. We then extrapolated the number of lung cancer cases to future silicosis cases, using the ratio of lung cancer to silicosis cases found in past cohort studies. Finally, we estimated the effect of various intervention scenarios on the future burden of lung cancer and silicosis.

Findings

From a cohort of 18,770,982 adult Australians in 2016, it is estimated that 5.4% (n≈1,022,150) will develop lung cancer over their lifetime, of which 1.0% (n≈10,390) are attributable to occupational exposure to RCS.

When extrapolated to silicosis, we estimated that between 83,090 and 103,860 cases of silicosis would result from current occupational exposure to RCS.

Modelling of interventions for occupational RCS exposure demonstrated that higher order controls (specifically elimination) are likely to have the most impact, as expected. However, modelling also demonstrated that significant impact can still be achieved with the use of administrative and engineering controls (when the latter is used together with respiratory protective equipment which meets recognised quality standards and is worn correctly).

Among those exposed to RCS from engineered stone, a similar pattern was seen, with the highest number of avoided cases resulting from elimination and engineering controls (specifically the use of on-tool extraction), when the latter is used together with well-fitted respiratory protective equipment.

Limitations

The FEF method used in this analysis provides an estimate of the proportion of projected lung cancers only in those who were exposed to RCS at work in the index year (2016). This therefore excludes cancers for those who were unexposed in 2016 but had been exposed in the past or could be exposed in the future. That is, this estimate does not take into account exposures over the entire work history. Secondly, the exposure prevalence used here is a best estimate based on an amalgam of data sources, as there is no comprehensive database of occupational RCS exposures in Australia available. Due to limitations in this data, we were not able to comprehensively include exposures in some industries, most notably tunnel construction. Both of these factors would result in an underestimate of exposure, and hence of the future attributable burden of lung cancer and silicosis. We also had limited information available on the baseline use of control measures, on which the modelling of interventions is based, and so the numbers presented here need to be interpreted with caution.

There are also some assumptions inherent in the FEF method. By using current prevalence of exposure, we assumed a range of exposures in terms of both level and duration. We also assumed that our risk estimates related to a range of exposures, however the extent to which these risk estimates relate to our estimated exposures is unclear. We did not include a latency period in our estimates, as we assumed that some of those exposed in the index year had been exposed for some time in the past and so may develop cancer soon after the index year.

Policy implications

The results presented in this report provide the best available estimate of the future number of lung cancer and silicosis cases arising from occupational exposure to RCS, as well as which intervention strategies are likely to be most successful in preventing these occupational diseases. These lead to clear opportunities for policy action.

Approximately 1.0% of projected lung cancer cases could be expected to occur in the subgroup of the current Australian adult population exposed to RCS at work, as a result of their exposure. This amounts to around 10,390 cancers. In addition, between 83,090 and 103,860 silicosis cases are expected to result from current RCS exposure.

While higher order interventions were generally estimated to be most effective in the examples modelled here, significant numbers of lung cancers could also be avoided by increasing the use of lower order controls. The results of this study can be used to show which intervention strategies may be most useful.

Further research

This report has provided an estimate of the future burden of lung cancer and silicosis attributable to current exposure to RCS, using the FEF approach. While we have used the best available data, further research could provide a more accurate picture of current RCS exposure as well as more detailed examination of the risk of silicosis and other diseases related to RCS exposure (e.g. autoimmune disease). Future research could also investigate the impact of additional intervention strategies on the future burden of disease arising from occupational exposure to RCS.

The current report represents a starting point, and estimates may be improved in future research as better information regarding exposure prevalence, risk estimates, baseline use of control measures, and future disease incidence projections becomes available.

1. INTRODUCTION

Crystalline silica is found naturally in many building and construction products, including sand, soil, stone, concrete, and mortar, and is also used in the manufacture of building products such as bricks, tiles, and glass.[1] It is known to be an aggressive and lung-damaging dust. The hazardous effects of exposure occur where dust particles are small enough to deposit within the lungs; that is, when particles are smaller than 10μm in diameter.[2] These particles are considered respirable; hence 'respirable crystalline silica' (RCS).

Exposure to RCS occurs when products containing crystalline silica, such as stone, rocks, concrete and bricks, are cut, sawn, ground, drilled, crushed, or otherwise processed.[1] Given the wide use of products containing silica, occupational exposure to RCS may occur in various industries, including mining and quarrying, construction trades, and glass and ceramics manufacture.[3, 4] A survey we conducted in 2012 found that 6.6% of the Australian workforce (329,000 workers) were exposed to RCS, with exposure particularly common among miners and quarryworkers (91.7% exposed) and construction workers (80.0% exposed).[5] Since the time this survey was undertaken, government investment into infrastructure has increased dramatically, leading to an increasing number of workplaces with RCS exposures.[6] In addition, the use of engineered stone has increased considerably since this time.[7]

RCS exposure has been linked to a variety of health effects, including silicosis, lung cancer, and autoimmune diseases.[8] When RCS particles are inhaled, they deposit and accumulate in the lung tissue, resulting in inflammation and scarring. The most common lung disease associated with RCS exposure is silicosis, a progressive and irreversible condition where healthy lung tissue is replaced by fibrotic tissue.[9] Worldwide, silicosis has been estimated to contribute 10,400 deaths and 210,000 years of life lost per year.[10] In Australia, a study conducted in 1992 predicted that 1,010 silicosis cases would occur over 40 years.[11] However, this was before the introduction of engineered stone, and there is currently no clear understanding as to the true incidence of silicosis in Australia.

Exposure to RCS has also been found to be associated with lung cancer, with the International Agency for Research on Cancer (IARC) classifying crystalline silica as a Group 1 (definite) carcinogen in 1997 and 2012.[12] Recently, studies have attempted to quantify the burden of lung cancer arising from occupational exposure to RCS. In Canada, 570 cases of cancer per year (2.4% of lung cancer cases) are estimated to be due to past exposure to RCS,[13] while in the UK, past exposure to silica was found to be responsible for 907 cancer registrations (2.4%) in 2004.[14] These studies estimate the number of lung cancer cases in one year thought to be attributable to exposure to RCS in the past. We have developed a novel method based on the lifetime risk approach,[15] the Future Excess Fraction (FEF) method,[16] which instead estimates the number of cancer cases over a number of years attributable to exposure to RCS in one year (Figure 1). This method is more useful in policy making and priority setting as it relates to contemporary rather than past exposures.

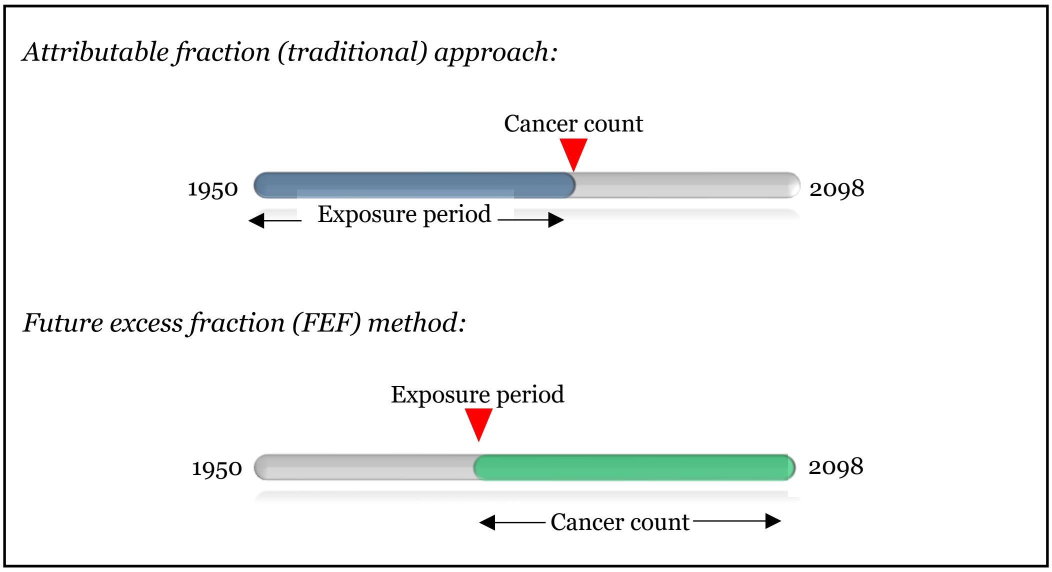

Figure 1. Traditional burden approaches versus Future Excess Fraction (FEF) method

In our 2017 study using the FEF method, we estimated the number of lung cancer cases occurring in the future which could be attributed to current exposure to RCS and found that 5,500 future cases of lung cancer were attributable to RCS exposure, representing 0.8% of all future cases.[17] However, this estimate did not account for exposure to RCS arising from engineered stone or tunnel construction, which are likely to be significant contributors to the burden of lung cancer in the future. There is also a very limited understanding of how many cases of silicosis might occur in the future as a result of current exposure to RCS in the workplace.

We aimed to quantify the future burden of lung cancer and silicosis cases which may arise due to occupational exposure to silica. Specifically, we aimed to:

a. estimate how many future lung cancers over the lifetime of the population might be caused by current exposure to RCS;
b. extrapolate this to the number of future silicosis cases that may arise;
c. estimate the number of future lung cancer cases that may be avoided under various intervention scenarios; and
d. extrapolate this to the number of future silicosis cases that would be avoided.

2. METHODS

2.1 Overview of the FEF method

The future excess fraction (FEF) method estimates the proportion of cancers occurring over a number of years in the future (i.e. 2016-2098) in those people who were exposed in a specific year (i.e. 2016) as a result of their exposure.[16] This method is based on the lifetime risk approach[15] and requires:

a. an estimate of the proportion of the population currently exposed to RCS at work;
b. a relative risk estimate for the association between RCS exposure and lung cancer; and
c. an estimate of future lung cancer incidence.

We can then use the ratio of lung cancer to silicosis cases found in past cohort studies to extrapolate the number of future lung cancer cases to future silicosis cases.

The FEF method can also be used to model the effect of different intervention scenarios on the future burden of disease.

2.2 Data sources

Data required for this analysis are outlined in Table 1 and explained in further detail below.

Future risk (person-years) calculations

The cohort for this study was defined as the adult population in 2016, as this was the most recent Census data available.[A] A matrix showing the proportion of individuals who reach each future age without either dying or being diagnosed with lung cancer was first calculated using a double decrement table. This matrix was then multiplied by the number of people in the population in 2016 (the 2016 mid-year population statistics obtained from the Australian Bureau of Statistics (ABS)) to obtain the future person-years at risk for the cohort. All calculations were conducted separately by sex.

Lung cancer incidence

Lung cancer incidence data was obtained from the Australian Institute of Health and Welfare (AIHW). The latest available data were from 2017. To project forward from 2017 to 2098, we used the 2017 incidence rate multiplied by the ABS population projections by age and sex. That is, we assumed constant incidence rates over time.

[A] Note that this estimate refers to the adult population, rather than the working population, as the incidence of cancer in the working population is not known. We have used the adult population in our previous modelling exercises. This means that the estimate presented here is an underestimate of the proportion of cancers due to occupation in the working population.

Table 1. Required data and sources

Data required	Details	Source
Number of people in cohort ($N_{p(t=0)}$)	2016 Australian adult population divided into five-year age bands, stratified by sex	ABS Census 2016
Double decrement table	Life table showing proportion of persons surviving in the population between exact age *x* and exact age *x+1*, truncated by death and first diagnosis of lung cancer	Calculated using life expectancy data from ABS, population numbers from ABS, and cancer incidence data from AIHW
Person-years at risk (*PY*)	2016 mid-year population multiplied by a matrix of future individual person-years truncated according to double decrement table	ABS Census 2016 and as calculated above
Cancer incidence rates (*R*)	Age- and sex-specific lung cancer incidence rates (most recent available)	AIHW
Future population numbers	Projected population divided into five-year age bands, stratified by sex, for use in calculating future cancer incidence	ABS
Total number of lung cancers in cohort	Age- and sex-specific incidence rates multiplied by age- and sex-specific person-years at risk	Calculated
Risk estimates (*RE*)	Risk estimates for association between RCS exposure and lung cancer	2020 pooled analysis of 16,901 lung cancer cases and 20,965 controls[18]
Number of people exposed ($N_{e(t=0)}$)	Prevalence of exposure to RCS	AWES 2012 nationwide survey[5, 19] supplemented with data from ABS Census 2016
Ratio of lung cancer to silicosis cases	Ratio of lung cancer cases to silicosis cases found in published cohort study to be used to extrapolate future lung cancer to silicosis cases	Cohort study of 34,018 silica exposed workers;[20] Pooled cohort study of 65,999 workers internationally[21]
Baseline level of use of controls	Prevalence of use of control measures to be used as baseline in modelling interventions	AWES[5, 19] and May 2021 Dust Disease research update by Quantum Research[22]

ABS: Australian Bureau of Statistics; AIHW: Australian Institute of Health and Welfare; AWES: Australian Work Exposures Study; RCS: Respirable Crystalline Silica

Risk estimate

The risk estimate for the association between RCS exposure and lung cancer was obtained from a recent pooled analysis of case-control studies conducted in Europe and Canada.[18] These studies used SYNJEM to assign historical silica exposures. We used the odds ratios for lowest (>0-0.39mg/m^3; OR=1.15, 95% CI 1.04-1.27) and highest (≥2.4 mg/m^3; OR=1.45, 95% CI 1.31-1.60) cumulative exposure to represent low and high levels of exposure, respectively.

Prevalence of exposure

We used data from the Australian Work Exposures Study (AWES) conducted in 2012 supplemented by more recent data from the 2016 Census (as outlined in Table 1) to obtain an estimate of the current prevalence of exposure to occupational RCS.

AWES was a nationwide telephone survey investigating prevalence of work-related exposure to carcinogens, including RCS, in Australia among 5,023 workers in 2011-2012.[19] AWES provided an estimate of the prevalence of exposure to RCS at work. Information about the level of exposure was also included, enabling the exposed population to be divided into a 'low' group (those assessed as having a 'low' or 'medium' level of exposure to RCS) and a 'high' group (those assessed as having a 'high' level of exposure to RCS; that is, exposure requiring the use of additional control measures). These levels are qualitative and refer to the level of exposure while undertaking relevant tasks, rather than the time-weighted average exposure of that person. An example of a task resulting in 'low' exposure was ploughing soil whilst in an enclosed cab, while cutting, grinding, or sanding concrete without protective measures was a task resulting in 'high' exposure. We extrapolated the prevalence and level of exposure to RCS found in AWES to the 2016 adult population. Extrapolations were conducted separately by occupational group and sex.

Silicosis due to engineered stone was only reported after AWES was completed,[7] and so AWES did not comprehensively cover exposure to RCS among those working with engineered stone. Therefore, we supplemented the AWES data with data from the 2016 Census which showed the number of people employed as bricklayers and stonemasons (ANZSCO code 3311) as well as data from recent reports from New South Wales[1] and Victoria[23] estimating the number of stonemasons exposed to engineered stone. Based on these data sources, we assumed that 20% of workers in ANZSCO code 3311 would be employed as stonemasons and would be exposed to engineered stone. These workers were assumed to have been excluded from AWES exposure estimates. Further, based on the Quantum Market Research Dust Disease Research Final Report[22] (see below), we assumed that 60% of stonemasons did not use adequate controls and thus were exposed to RCS at a high level, with the remainder (40%) exposed at a low level.

It is also likely that workers exposed to RCS through tunnel construction were excluded from AWES exposure estimates. However, as there is no ANZSCO code dedicated to these workers, we were unable to include them in a similar way.

Extrapolation of numbers to silicosis cases

As there is no comprehensive data concerning the incidence of silicosis in Australia, the FEF method could not be used to predict the number of future silicosis cases arising from current exposure to RCS. We instead assumed that the ratio of lung cancer to silicosis cases in the Australian adult population would be similar to the ratio found in a 2018 pooled cohort study.[21] This study used data on 65,999 workers internationally and estimated that 1.6% of the cohort died from lung cancer while 13% developed silicosis, a ratio of approximately 1:8. No data was provided as to the stage or type of silicosis. Therefore, we multiplied the number of lung cancer cases estimated to result from current RCS exposure by 8 to arrive at an estimated number of silicosis cases.

A 2013 cohort study of 34,018 silica-exposed workers in China followed up over 44 years found 5,297 silicosis cases and 546 lung cancer deaths;[20] that is, a ratio of approximately 1:10. We therefore conducted a sensitivity analysis, multiplying the number of lung cancer cases by 10 to provide an upper limit to the estimated number of attributable silicosis cases.

We followed this same method to estimate the number of silicosis cases which would be avoided by various interventions.

Use of control measures

Baseline data on use of controls to prevent RCS exposure was obtained from AWES in the first instance. Where this data was not available in AWES (for example, use of controls among engineered stone workers), we used data from the Quantum Market Research Dust Disease Research Final Report, submitted to the National Dust Disease Taskforce.[22] This report, prepared in May 2021, provides the results of a survey of 350 silica-exposed tradespeople. It found that 60% of stonemasons and 73% of other tradespeople feel that their exposure to silica is not completely under control. This report also provides the prevalence of use of a range of control measures, including ventilation, water suppression, on-tool extraction, and respirators. We assumed this level of use as the baseline level of control use when modelling various intervention scenarios. That is, we assumed that the level of use reported in this survey was that in use when the exposure prevalence information was collected, and so any changes to the use of control measures was applied to this baseline.

2.3 Statistical analysis

The FEF method was used to estimate the proportion of future work-related lung cancers which could be expected to occur among Australian workers currently exposed to RCS at work, as a result of their exposure. The detailed statistical methodology is available elsewhere.[16] In simple terms, the following steps were followed:

1) Calculate the general lifetime risk (expressed as a percentage) of lung cancer in the Australian population irrespective of exposure, using estimated person-years at risk *(PY)* and age- and sex-specific incidence rates *(R)* divided by the number of people in the cohort $(N_{p(t=0)})$:

$$LR_P = \frac{R \times PY}{N_{p(t=0)}}$$

2) Calculate the excess lifetime risk of lung cancer due to exposure to RCS (LR_x) using the formula:

$$LR_x = \frac{LR_p \times N_p \times (RR - 1)}{N_p + \left(N_e \times (RR - 1)\right)}$$

where $LR_p \times N_p$ is the number of expected lung cancers in the population; $RR\text{-}1$ is the excess risk of lung cancer associated with exposure to RCS; and N_e is the number of people exposed to RCS at work.

3) Estimate the number of excess lung cancers (future excess number, or FEN) attributable to exposure to RCS, by multiplying LR_x by N_e. These calculations are conducted separately by exposure level and then summed to give an overall FEN.

4) Estimate the FEF by dividing the FEN by the total expected number of lung cancer cases in the population ($LR_p \times N_p$).

Extrapolation to silicosis cases

We multiplied the FEN of lung cancer cases attributable to occupational RCS exposure by a factor of 8 to estimate the future number of silicosis cases due to RCS exposure. We also estimated an upper limit of estimated silicosis cases by using a factor of 10. This provided a range of possible estimates for the number of future silicosis cases attributable to current occupational exposure to RCS. This method was also used to estimate the number of silicosis cases which would be avoided by various interventions (see below).

Modelling interventions

The FEF method was also used to model changes in the future number of lung cancer and silicosis cases which would result from the successful implementation of various workplace and policy interventions aimed at reducing or eliminating occupational RCS exposure. To do this, we modified the estimated number of workers completing particular tasks or using certain protective measures, and therefore modified the prevalence and/or level of exposure to RCS. All other data inputs remained constant, and analysis followed the steps outlined above.

The interventions modelled were based on the hierarchy of control model[24] and chosen based on guidance documents for managing RCS exposure[25] as well as advice from the Australian Council of Trade Unions (ACTU). We used the proportion of people reporting the use of certain control measures in AWES[19] and/or the Quantum Market Research Dust Disease Research Final Report[22] as a baseline, and applied changes to the use of control measures to this baseline. In some cases, the use of control measures was reported in the Quantum report as a mean value on a six-point Likert scale (from 0 never to 5 always), in which case we assumed a normal distribution to calculate the proportion who scored a 4.6 or above (corresponding to *always*).

All numbers were rounded to the nearest 10 to avoid a false sense of precision.

3. RESULTS

3.1 Prevalence of occupational exposure to RCS

We estimated that approximately 584,050 Australian workers are currently exposed to RCS in the workplace. The vast majority of exposed workers are male, with an estimated 554,375 males and 39,675 females exposed to RCS at work. Exposures were relatively evenly distributed between high and low levels, with 47.4% (n=276,909) of exposed workers exposed at a high level, and 52.6% (n=307,141) at a low level. Females were more likely to be exposed at a low level (n=34,233) than a high level (n=5,442), while the distribution among male workers was more even (271,467 exposed at a high level, 272,908 low level).

3.2 Total number of predicted lung cancers in cohort

Our cohort of the Australian adult population in 2016 was estimated to number 18,770,982 in total (9,219,712 males and 9,551,270 females). An estimated 1,022,150 lung cancers were predicted to occur over their lifetime, 579,780 in males and 442,370 in females, regardless of exposure.

3.3 FEF of lung cancer attributable to RCS exposure

Overall, we estimate that 1.02% (n=10,390) of predicted future lung cancer registrations could arise among all workers who were exposed to RCS at work in 2016, as a result of their exposure. The majority of these cancers were estimated to occur among males, with 1.73% (n=10,040) of predicted future lung cancers in males estimated to be attributable to occupational RCS exposure. Among females, 0.08% (n=350) of predicted future lung cancers were estimated to be attributable to occupational RCS exposure.

When looking at high exposures only, a total of 0.74% (n=7,600) of predicted future lung cancer registrations were estimated to be attributable to high levels of RCS exposure. This comprises 7,480 cancers among males (1.29% of all future lung cancers) and 110 cancers among females (0.03%).

3.4 Future silicosis cases due to RCS exposure

When applying the ratio of lung cancer to silicosis cases found in a previous pooled cohort study[21] (1:8), we estimate that 83,090 silicosis cases will arise in the future as a result of current occupational exposure to RCS. Using the less conservative ratio of 1:10 found in a Chinese cohort study,[20] we estimate that 103,860 silicosis cases will result from current occupational RCS exposure. We expect that the true estimate lies somewhere in this range (83,090-103,860).

3.5 Impact of interventions

We also modelled the impact of a variety of theoretical interventions that may be utilised to reduce the future burden of lung cancer due to occupational RCS exposure. These interventions were based on the hierarchy of controls model as well as guidance documents and expert advice. The interventions modelled were as follows (Table 2):

1) Reducing the level of exposure to silica among workers in the construction or mining industry (modelled separately) to general population (background) levels. This removes excess risk attributable to RCS exposure in those workers.
2) Engineering controls: Dust suppression to be used on all mine and/or construction sites (modelled separately and together), together with the use of well-fitted quality respiratory protective equipment. Assuming 100% compliance to the use of a Respiratory Protection Program under Standard AS1715-2009, this removes background exposure to RCS for those not completing any specific tasks leading to RCS exposure.
3) Engineering controls: Wet cutting methods to be used during all concrete cutting and grinding tasks), together with the use of well-fitted quality respiratory protective equipment. Assuming 100% compliance, this reduces RCS exposure for this task to a low level.
4) Administrative controls: Restricting worker access to areas on mine sites near the crusher (reduced to 75%, 50%, and 25% of currently exposed). This removes the potential for RCS exposure attributable to this task, although workers may still be exposed through the completion of other tasks.

We also modelled a variety of interventions specific to engineered stone (Table 3). These comprised:

1) Elimination: Completely removing the source of exposure among all stonemasons (i.e. banning the import and use of engineered stone). This removes all potential for exposure to RCS in these workers.
2) Engineering controls: Wet cutting methods to be used during all cutting of engineered stone), together with the use of well-fitted quality respiratory protective equipment. Assuming 100% compliance to the use of a Respiratory Protection Program under Standard AS1715-2009, this reduces RCS exposure for this task to a low level.
3) Engineering controls: On-tool dust extraction to be used during all cutting of engineered stone, together with the use of well-fitted quality respiratory protective equipment. Assuming 100% compliance, this reduces RCS exposure for this task to a low level.

4) Engineering controls: All cutting of engineered stone to be completed in a well-ventilated area (i.e. using local extraction), together with the use of well-fitted quality respiratory protective equipment. Assuming 100% compliance, this reduces RCS exposure for this task to a low level.
5) Administrative controls: Exclusion zones to be erected and adhered to around engineered stone cutting areas. This removes background exposure to RCS, although workers may still be exposed through the completion of other tasks.

As seen in Tables 2 and 3, higher order interventions (and particularly those removing all potential for exposure) were estimated to have the greatest effect on future lung cancer and silicosis cases, although interventions at all levels of the hierarchy of control were predicted to have some effect. The greatest impact was seen from reducing exposure to RCS among workers in the construction industry to general population (background) levels (6,720 lung cancers and 52,730 to 74,500 silicosis cases avoided). The use of dust suppression on construction and mine sites was also predicted to be particularly effective, assuming it was used alongside well-fitted respiratory protective equipment, with 1,380 lung cancers and 11,010 to 13,760 silicosis cases estimated to be avoided. It should be noted that engineering controls alone are not sufficient to reduce exposure to RCS below the relevant workplace exposure limits, and so these controls must be used along with well-fitted respiratory equipment in order to be effective.

A similar pattern was observed among interventions aimed specifically at engineered stone, with elimination of all exposure to engineered stone seen to be the most effective intervention (100 lung cancers and 770 to 960 silicosis cases avoided). Engineering controls, and specifically the use of on-tool extraction, was also estimated to be particularly effective when used alongside well-fitted respiratory equipment, with 50 lung cancers and 370 to 460 silicosis cases avoided. This is likely to reflect, at least in part, the very low level of baseline use of this control (2% estimated to currently always use on-tool extraction).

Table 2. Forecasted estimated avoidable numbers of lung cancer and silicosis cases under various intervention scenarios to reduce the prevalence of exposure to respirable crystalline silica

Intervention	**Future excess fraction (%)**	**Future excess number (n)[a]**	**Lung cancers avoided (n)[a]**	**Silicosis cases avoided (range)[a]**
Baseline *(n exposed = 584,050)*	1.02	10,390	-	-
Reducing exposure to population levels				
1A. Reducing exposure in construction industry *(current n exposed = 324,420)*	0.36	3,670	6,720	52,730 - 74,500
1B. Reducing exposure in mining industry *(current n exposed = 137,380)*	0.78	8,010	2,380	19,010 - 23,760
Engineering controls (together with RPE)				
2A. Dust suppression on all construction sites *(current n exposed = 200,160)*	0.96	9,840	550	4,370 - 5,460
2B. Dust suppression on all mine sites *(current n exposed = 130,010)*	0.94	9,600	790	6,290 - 7,860
2C. Dust suppression on all construction and mine sites *(current n exposed = 330,170)*	0.88	9,010	1,380	11,010 - 13,760
3. Wet cutting methods during all concrete cutting and grinding *(current n exposed = 160,100; current proportion using wet cutting = 4%)*	0.95	9,750	640	5,090 - 6,360
Administrative controls				
4A. Reduce number of workers in areas near mine site crushers to 75% of current *(current n exposed = 51,790; reduced to n = 38,840)*	0.99	10,140	250	1,970 - 2,460
4B. Reduce number of workers in areas near mine site crushers to 50% of current *(reduced to n = 25,890)*	0.97	9,890	500	3,970 - 4,960
4C. Reduce number of workers in areas near mine site crushers to 25% of current *(reduced to n = 12,950)*	0.94	9,640	750	5,970 - 7,460

[a] All numbers rounded to the nearest 10.

Table 3. Forecasted estimated avoidable numbers of lung cancer and silicosis cases under various intervention scenarios to reduce the prevalence of exposure to RCS from engineered stone

Intervention	**Future excess fraction (%)**	**Future excess number (n)[a]**	**Lung cancers avoided (n)[a]**	**Silicosis cases avoided (range, n)[a]**
Baseline *(n exposed = 584,050)[b]*	1.02	10,390	-	-
Elimination				
1. Eliminating all engineered stone exposure *(current n exposed = 4,610)*	1.01	10,290	100	770 - 960
Engineering controls (together with RPE)				
2. Wet cutting methods for all engineered stone *(current proportion using wet cutting = 18%)*	1.01	10,350	40	290 - 360
3. On-tool dust extraction for all engineered stone cutting *(current proportion using on-tool extraction = 2%)*	1.01	10,340	50	370 - 460
4. All cutting of engineered stone to be completed in well ventilated area *(current proportion using ventilation = 34%)*	1.01	10,360	30	210 - 260
Administrative controls				
5. Exclusion zones to be set up around engineered stone cutting areas *(current proportion using exclusion zones = 39%)*	1.02	10,370	20	130 - 160

[a] All numbers rounded to the nearest 10.

[b] Note this represents exposure to all forms of RCS.

4. ASSUMPTIONS AND LIMITATIONS

The results presented here, while providing the best available estimate of the future number of lung cancer and silicosis cases arising from occupational exposure to RCS, are subject to a range of assumptions.

The FEF method used in this analysis provides an estimate of the proportion of projected lung cancer and silicosis cases only in those who were exposed to RCS at work in the index year (2016). This therefore excludes cases among those who were unexposed in 2016 but had been exposed in the past or could be exposed in the future. That is, this estimate does not take into account exposures over the entire work history. By using current prevalence of exposure, we assumed a range of exposures in terms of both level and duration. We did not include a latency period in our estimates, as we assumed that some of those exposed in the index year had been exposed for some time in the past and so may develop disease soon after the index year.

Further, the exposure prevalence used here is a best estimate based on an amalgam of data sources, as there is no comprehensive database of occupational RCS exposure in Australia available. Since the time when AWES was conducted (2011-2012), there has been a dramatic increase in government investment into infrastructure,[6] leading to an increasing number of workplaces with RCS exposures. We were not able to comprehensively include exposures in some of these industries, most notably tunnel construction, and so the estimate of exposure prevalence here is likely an underestimate.

In addition, the use of engineered stone has increased considerably since the time when AWES was conducted. We therefore assumed that AWES did not capture exposure to engineered stone, and so supplemented this data with Census data showing the number of people employed as bricklayers and stonemasons (ANZSCO code 3311). In doing so, we assumed that 20% of people in this code would be employed as stonemasons and using engineered stone, and further that 60% of those were exposed at a high level. The accuracy of these assumptions is unknown.

Future lung cancer cases were projected forward based on demographic change only, using population projections estimated by ABS, and thereby assuming constant incidence rates. We have done some modelling around this in the past and found this method to produce a slightly higher future excess fraction (FEF) than projections which account for historical incidence trends.

We also assumed that the risk estimates we used related to a range of exposures and were relevant to currently exposed workers in Australia. However, the extent to which these risk estimates relate to our estimated exposures is unclear.

In extrapolating to the number of silicosis cases, we assumed a ratio of lung cancer to silicosis cases based on the literature. This literature was based on past exposure to RCS and its relevance to current exposures and disease incidence in Australia is unclear. However, there is no comprehensive data capturing the prevalence of silicosis in Australia, and so this was the best estimate available.

We also had limited information available on the baseline use of control measures, on which the modelling of interventions is based, and so the numbers presented here need to be interpreted with caution.

5. CONCLUSIONS

The results presented in this report provide the best available estimate of the future number of lung cancer and silicosis cases arising from occupational exposure to RCS, as well as which intervention strategies are likely to be most successful in preventing these occupational diseases. These lead to clear opportunities for policy action.

Approximately 1.02% of projected lung cancer cases could be expected to occur in the proportion of the current Australian adult population exposed to RCS at work, as a result of their exposure. This amounts to approximately 10,390 cancers. In addition, between 83,090 and 103,860 silicosis cases are expected to result from current RCS exposure.

While higher order interventions were generally estimated to be most effective in the examples modelled here, significant numbers of lung cancers could also be avoided by increasing the use of lower order controls. The results of this study can be used to show which intervention strategies may be most useful.

The current report represents a starting point, and estimates may be improved in future research as better information regarding exposure prevalence, risk estimates, baseline use of control measures, and future disease incidence projections becomes available.

REFERENCES

1. James M and Martin R. *Case finding study - Respirable crystalline silica exposure in the NSW manufactured stone industry*. 2021. North Sydney: Golder Associates.

2. Australian Institute of Occupational Hygienists. *Respirable crystalline silica and occupational health issues*. 2018. Tullamarine: AIOH.

3. Ophir N, Shai AB, Alkalay Y, et al. Artificial stone dust-induced functional and inflammatory abnormalities in exposed workers monitored quantitatively by biometrics. *ERJ Open Res* 2016; 2 DOI: 10.1183/23120541.00086-2015.

4. Steenland K and Ward E. Silica: A lung carcinogen. *CA Cancer J Clin* 2014; 64: 63-69. DOI: 10.3322/caac.21214.

5. Si S, Carey RN, Reid A, et al. The Australian Work Exposures Study: Prevalence of occupational exposure to respirable crystalline silica. *Ann Occup Hyg* 2016; 60: 631-637. DOI: 10.1093/annhyg/mew007.

6. Infrastructure Partnerships Australia. *Australian Infrastructure Budget Monitor 2021-2022*. 2022. Sydney: Infrastructure Partnerships Australia.

7. Hoy RF, Baird T, Hammerschlag G, et al. Artificial stone-associated silicosis: A rapidly emerging occupational lung disease. *Occup Environ Med* 2018; 75: 3-5. DOI: 10.1136/oemed-2017-104428.

8. Hoy RF and Chambers DC. Silica-related diseases in the modern world. *Allergy* 2020; 75: 2805-2817. DOI: 10.1111/all.14202.

9. Kramer MR, Blanc PD, Fireman E, et al. Artificial stone silicosis: Disease resurgence among artificial stone workers. *Chest* 2012; 142: 419-424. DOI: 10.1378/chest.11-1321.

10. Naghavi M, Abajobir AA, Abbafati C, et al. Global, regional, and national age-sex specific mortality for 264 causes of death, 1980-2016: A systematic analysis for the Global Burden of Disease Study 2016. *Lancet* 2017; 390: 1151-1210. DOI: Doi 10.1016/S0140-6736(17)32152-9.

11. Nurminen M, Corvalan C, Leigh J, et al. Prediction of silicosis and lung cancer in the Australian labor force exposed to silica. *Scandinavian Journal of Work Environment & Health* 1992; 18: 393-399. DOI: DOI 10.5271/sjweh.1565.

12. International Agency for Research on Cancer. *Silica dust, crystalline, in the form of quartz or cristobalite*. 2012. Lyon: IARC.

13. CAREX Canada. Silica (crystalline) occupational exposures, https://www.carexcanada.ca/profile/silica_crystalline-occupational-exposures/ (2022, accessed 8 March 2022).

14. Brown T, Darnton A, Fortunato L, et al. Occupational cancer in Britain. Respiratory cancer sites: Larynx, lung and mesothelioma. *Br J Cancer* 2012; 107 Suppl 1: S56-70. DOI: 10.1038/bjc.2012.119.

15. Bender AP, Punyko J, Williams AN, et al. A standard person-years approach to estimating lifetime cancer risk. *Cancer Causes Control* 1992; 3: 69-75. DOI: 10.1007/BF00051915.

16. Fritschi L, Chan J, Hutchings SJ, et al. The future excess fraction model for calculating burden of disease. *BMC Public Health* 2016; 16: 386. DOI: 10.1186/s12889-016-3066-1.

17. Carey RN, Hutchings SJ, Rushton L, et al. The future excess fraction of occupational cancer among those exposed to carcinogens at work in Australia in 2012. *Cancer Epidemiol* 2017; 47: 1-6. DOI: 10.1016/j.canep.2016.12.009.

18. Ge C, Peters S, Olsson A, et al. Respirable crystalline silica exposure, smoking, and lung cancer subtype risks: A pooled analysis of case-control studies. *Am J Respir Crit Care Med* 2020; 202: 412-421. DOI: 10.1164/rccm.201910-1926OC.

19. Carey RN, Driscoll TR, Peters S, et al. Estimated prevalence of exposure to occupational carcinogens in Australia (2011-2012). *Occup Environ Med* 2014; 71: 55-62. DOI: 10.1136/oemed-2013-101651.

20. Liu Y, Steenland K, Rong Y, et al. Exposure-response analysis and risk assessment for lung cancer in relationship to silica exposure: A 44-year cohort study of 34,018 workers. *Am J Epidemiol* 2013; 178: 1424-1433. DOI: 10.1093/aje/kwt139.

21. Keil AP, Richardson DB, Westreich D, et al. Estimating the impact of changes to occupational standards for silica exposure on lung cancer mortality. *Epidemiology* 2018; 29: 658-665. DOI: 10.1097/EDE.0000000000000867.

22. Quantum Market Research. *Dust disease research update: Final report*. 2021. South Yarra: QMR.

23. Monash University. *Final report of phase 2: Silica-associated lung disease health screening research project*. 2021. Victoria: Monash University.

24. Lyon BK and Popov G. Risk treatment strategies: Harmonizing the hierarchy of controls and inherently safer design concepts. *Professional Safety* 2019; 64.

25. Safe Work Australia. Choosing and implementing control measures for silica dust, https://www.safeworkaustralia.gov.au/safety-topic/hazards/crystalline-silica-and-silicosis/choosing-and-implementing-control-measures-silica-dust (accessed 9 March 2022).