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Respirable Crystalline Silica Exposures among Stoneworkers involved in Stone Restoration Work

A thesis submitted to the National University of Ireland Galway
For the degree of
Doctor of Philosophy
by

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Abstract

Exposure to respirable crystalline silica (RCS) can result in the development of a range of adverse health effects including silicosis and lung cancer. Although exposure to RCS has been characterised in many occupational groups, limited data is available on RCS exposures and suitable exposure controls in restoration stone work. Occupational exposure to RCS in this sector is of particular concern due to the high silica content of the materials used, the challenges in implementing exposure control strategies and the large number of workers potentially affected globally. The objectives of this study were to identify the main determinants of RCS exposure of a group of restoration stoneworkers and to design and execute a workplace intervention to reduce worker exposure to RCS during high exposure tasks. During the exposure assessment, field trials were performed to evaluate the performance of high-flow rate samplers for the collection and assessment of RCS in low silica content materials during restoration stone work.

An exposure assessment (*n*=103) study was designed to characterise RCS exposures amongst a group of stoneworkers involved in the restoration and maintenance of heritage buildings in Ireland. Exposure data was analysed using mixed effects modelling to investigate determinants of RCS exposure and their contribution to the individual's mean exposure. Between-depot, between-worker and within-worker variance components were also investigated. High risk RCS exposure tasks, involving angle grinders and sandstone were identified and a technical intervention study was designed to evaluate the effectiveness of commercially available shroud systems at reducing RCS levels. The workplace intervention also included a worker element, involving a questionnaire survey designed to collect information on exposure control usage and worker and organisational factors, influencing worker use of exposure controls. Post implementation of the workplace intervention, the questionnaire survey was re-administered and an exposure assessment was conducted. To investigate the implication of this study for the wider stoneworker community in Ireland, a questionnaire was administered to a convenience sample of stoneworkers. While conducting the exposure assessment at field sites, a short study to evaluate the performance of three high flow rate samplers for the collection of low concentrations of RCS in restoration stonework sites was also performed.

The geometric mean (GM) RCS exposure concentrations for all worker tasks ranged from < 0.02 - 0.70 mg/m^3 with concentrations for work involving limestone/lime mortar and sandstone < 0.02 - 0.01 mg/m^3 and < 0.02 - 0.70 mg/m^3 respectively. 67% of the 8-hr time weighted average (TWA) exposure measurements for sandstone exceeded the occupational exposure limit proposed for RCS, 0.05 mg/m^3. The 95 percentile for the tasks of cutting and grinding sandstone was greater than the OELV, demonstrating a high probability of non-compliance with the OELV when workers carried out these tasks. Statistical analysis of the data using mixed effects regression found task to be the only significant ($P < 0.001$) determinant of RCS exposure, with the tasks of grinding and cutting sandstone producing RCS exposures on average 32 and 70 times higher than the task of stone decorating. The variance components for between-depot, between–worker and within-worker were reduced by 46%, 89% and 49% respectively, after including task in the mixed effects model. The within worker variance component was larger than the between-depot and between worker variance components in the final model. Thus, the workplace intervention focused specifically on the worker task of grinding sandstone and took into account the within worker variability within this group. The Dustie® shroud was selected as the most suitable on-tool shroud, based on worker feedback, and respirable dust concentrations and RCS were both significantly reduced ($P < 0.001$) when the shroud was in place compared with concentrations without using the shroud. Regression analysis showed that there was a significant ($P < 0.001$) difference in the levels of respirable dust measured depending on grinding wheel used. A worker training programme was developed including hazard communication, information on exposure controls and the technical intervention. Post intervention task exposure data for grinding sandstone was lower (GM 0.5 mg/m^3) than exposure values measured prior to implementation of the Dustie® shroud (GM 0.7 mg/m^3). Post intervention workers exhibited a significant improvement in their knowledge of exposure controls and occupational health issues but use of the shroud and some individual barriers to using RPE did not show significant improvement. The fact that the sites were still in the commissioning phase of the intervention is a probable explanation for the low reporting of shroud use post intervention and suggests that the short time period of three months may not be sufficient time to observe a change within this organisation. Results from the survey of Irish stoneworkers showed that this population regularly worked with high silica content materials and nearly 90% used power tools with these materials. Findings also

indicated poor health and safety practice and a lack of awareness of the health risks associated with stone work amongst this group.

Results from the evaluations of the high flow samplers indicated that most of the quartz mass collected with the high-flow-rate samplers were above the limit of detection, relative to the corresponding low-flow-rate samplers used in the study. This indicated that these samplers were suitable for quantifying exposures from low silica content materials. Feedback received from the workers on the practicality of the high-flow pumps indicated that they were not comfortable to wear and could interfere with their work.

This study provides a comprehensive evaluation of exposure to RCS in restoration stone work, and contributes to existing knowledge on exposure controls suitable for this work, enabling professionals in identifying effective controls to reduce RCS exposures in their workplace. Results indicate that there is significant potential for over exposure to RCS amongst restoration stoneworkers and other stoneworkers who work with high silica content materials worldwide, putting them at risk of developing illnesses associated with RCS exposure. There is a need for regulatory bodies to produce more specialised health and safety guidance material for this sector, concentrations of RCS can be significantly reduced by using commercially available on-tool shrouds while grinding sandstone in restoration stone work, however, there is scope for commercially available on-tool shrouds to be further refined. Findings also indicated that worker behaviour had a role to play in the use of the shrouds post intervention and that a technical intervention alongside a behavioural intervention should be implemented with the aim of improving workplace intervention design.

Declaration

The work in this thesis is based on research carried out at the Centre for Climate and Air Pollution Studies (C-CAPS), School of Physics, National University of Ireland, Galway, Ireland. No part of this thesis has been submitted elsewhere for any other degree or qualification and is all my own work unless referenced to the contrary in the text

Dedication

I would like to dedicate this PhD to my parents

Ben and Marie

And to my husband

Mick

List of publications and presentations arising from this work

Peer reviewed papers

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2013) Respirable Crystalline Silica Exposures among Stone Workers in Ireland. Silica and Associated Respirable Mineral Particles, STP 1565, Martin Harper and Taekhee Lee, Eds., pp. 39–53, doi:10.1520/STP156520120219, ASTM International, West Conshohocken, PA 2013.

Coggins M, Healy C, Lee T, Harper M. (2013)Performance of High-Flow-Rate Samplers for Respirable Crystalline Silica Measurement Under Field Conditions: Preliminary Study. Silica and Associated Respirable Mineral Particles, STP 1565, Martin Harper and Taekhee Lee, Eds., pp. 125–138, doi:10.1520/STP156520120219, ASTM International, West Conshohocken, PA 2013.

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2014) Determinants of respirable crystalline silica (RCS) exposure among stone workers involved in stone restoration work. Ann Occup Hyg; 58(1): 6-18.

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2014) Evaluation of on-tool shrouds for controlling respirable crystalline silica in restoration stone work. Ann Occup Hyg (2014) doi: 10.1093/annhyg/meu069

Presentations and posters

Healy C, Coggins M, Van Tongeren M, Moore K (2010) Study of silica exposures among stone workers. An oral presentation at the ISO- TC146-SC2_WG7 (ISO Working Group on Silica Measurement) Silica Measurement Meeting at the Health and Safety Laboratory; May 11-12th 2010; Buxton UK.

Healy C, Coggins M, Van Tongeren M, Moore K (2011) Study of silica exposure among stone masons in Ireland. An oral presentation at the Occupational Hygiene Society of Ireland 20th Annual Conference; February 16th -17th 2011; Galway, Ireland.

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2011). Study of silica exposures among stone masons in Ireland. An oral presentation at the British Occupational Hygiene Society annual conference; April 5-7 2011; Stratford upon Avon, UK.

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2012) Study of respirable crystalline silica exposures among stoneworkers involved in stone restoration work. An oral presentation at X2012: 7th International Conference on the Science of Exposure Assessment; July 2-5 2012, Royal College of Physicians, Edinburgh, UK.

Coggins M, Healy C, Van Tongeren M, MacCalman L, McGowan P. (2012) Respirable crystalline silica exposures among restoration stonemasons. Oral presentation at the Second ASTM D22 Symposium on Silica and associated Respirable Mineral particles; October 25-26 2012, Atlanta, GA, USA.

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2013) Determinants of respirable crystalline silica exposures among stone workers involved in restoration work. A poster at the Inaugural UK and Ireland Exposure Science meeting; March 14th 2013; Edinburgh, UK.

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2013) Respirable crystalline silica exposures among restoration stone workers. Oral presentation at the centre for Health from Environment symposium; June 7th, Galway, Ireland

Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2014) Effective communication skills for restoration stoneworkers. Oral presentation at the Occupational Hygiene Society of Ireland 23rd Annual Conference; February 19th -20th 2014; Portlaoise, Ireland.

Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
ANOVA	Analysis of Variance
BSI	British Standards Institute
CCF	Custom Calibration Factor
CDC	Centre for Disease Control
CI	Confidence Interval
COPD	Chronic Obstructive Pulmonary Disease
CEN	Comite European de Normalisation
COSHH	Control of Substances Hazardous to Health
ECF	Existing Calibration Factor
EU	European Union
GLM	Generalised Linear Model
GLMM	Generalised Linear Mixed Model
GM	Geometric Mean
GSD	Geometric Standard Deviation
HSA	Health and Safety Authority
HSE	Health and Safety Executive
HSL	Health Safety Laboratory
IARC	International Agency for Research on Cancer
IOM	Institute of Occupational Medicine
IR	Infrared
ISO	International Organization for Standardisation
LEV	Local Exhaust Ventilation
LOD	Limit of Detection
LOQ	Limit of Quantification
MLE	Maximum Likelihood Estimation
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational Exposure Limit (s)
OELV	Occupational Exposure Limit Value(s)
OHSA	Occupational Safety and Health Association
PEL	Permissible Exposure Limit (s)

PM	Particulate Matter
PVC	Polyvinyl Chloride
RCS	Respirable Crystalline Silica
REL	Recommended Exposure Limit (s)
RPE	Respiratory Protective Equipment
SEG	Similarly Exposed Group
SD	Standard Deviation
SiO_2	Silicon Dioxide
SME	Small and Medium Sized Enterprises
TB	Tuberculosis
TLV	Threshold Limit Value (s)
TWA	Time Weighted Average
WASP	Workplace Analysis Scheme for Proficiency
WEL	Workplace Exposure Limits
WHO	World Health Organisation
XRD	X - Ray Diffraction

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Chapter 1.0 Introduction

Exposure to respirable crystalline silica (RCS) dust is associated with a wide range of diseases in particular silicosis, a debilitating and incurable fibrogenic lung disease and lung cancer (IARC, 1997). Respiratory illnesses associated with stone work have been recognised since the beginning of the 18th century (Ramazzini, 1940). Silicosis is one of the most ancient occupational illnesses (WHO, 2007), although regulation of occupational exposures at the current OEL has reduced rates of silicosis, new cases of silicosis and silica related lung cancer continue to be diagnosed in the developed world (Cherrie *et al.,* 2011; Money, 2012; HSE, 2013), some among younger workers who entered the workforce after the existing standard was in place (Steenland and Ward, 2014).

In the absence of effective specific treatment for silica-related diseases, the only approach remains primary prevention i.e. the control of exposure to RCS (ATS, 2007) therefore; the collection of exposure data from a diverse range of occupations is crucial. The introduction of a reduced OEL for RCS and its reclassification under the European Carcinogens Directive provides a powerful incentive for controlling exposure to RCS in the occupational environment (ACSHW, 2012; OSHA, 2013). Knowledge of RCS exposures in all potential exposure scenarios helps health and safety professionals make an informed decision about controlling exposure to RCS in their workplace. RCS exposure data exists for many occupational groups but is limited in restoration stone work which is of concern given the large number of workers potentially affected globally and the high silica content materials used in this work. Improved knowledge of RCS exposures in restoration stone work could have implication for millions of workers who may be at risk of developing a range of silica associated diseases.

This research was conducted amongst a group of restoration stoneworkers employed by the Heritage Services Division of the Irish Commissioners of Public Works in Ireland, the Irish government agency responsible for the management of state property in Ireland. Restoration stoneworkers are often required to work with materials containing high levels of crystalline silica which have been used for centuries in the construction of monuments in Ireland and across Europe alike. Preserving these monuments by using historically accurate materials in their restoration is paramount for agencies responsible for national monument restoration. While such strict conservation guidelines are desirable for conserving the historical integrity of the monument, it is not desirable for the stoneworkers responsible for the restoration of these monuments who are potentially exposed to stone dust containing RCS. This problem is exacerbated by the widespread use of power tools to increase productivity. Due to these strict conservation guidelines, restoration stoneworkers are an occupational group of particular concern from an RCS exposure point of view, due to the challenges in implementing traditional exposure control strategies. For this reason, the evaluation of engineering controls in this sector is paramount in order to contribute new information to the pool of research on exposure controls to reduce exposure to RCS.

Although many studies have established the effectiveness of exposure controls with concrete in the construction sector (Echt and Sieber, 2002; Akbar-Khanzadeh and Brillhart, 2002; Croteau *et al.*, 2004; Akbar-Khanzadeh *et al.*, 2007; 2010) few published studies have investigated exposure controls such as shrouds for use with high silica content materials such as sandstone (Tjoe Nij *et al.*, 2003). It is essential to investigate exposure controls suitable for the high silica materials and tools used by restoration stoneworkers. Often exposure controls suitable for stone work tasks in other sectors may not be suitable for restoration stone work. Also, previous research has not investigated incorporating other exposure controls such as administrative controls with the engineering control to reduce worker exposure to RCS.

While reducing the OELV for RCS would provide many health benefits to the workers exposed, there would difficulty demonstrating compliance with an OEL under 0.1 $mg.m^3$ especially in the case of short term measurements. Few studies (Stacey and Thorpe, 2009; NIOSH, 2010) have evaluated high-flow samplers which may be able to collect sufficient mass for subsequent silica analysis in real occupational environments. Research investigating the effectiveness of these samplers in real occupational environments enables the establishment of a suitable method of measurement to support enforcement activity of a lowered OELV.

This research aims to characterise the RCS exposure and investigate the contribution of determinants of RCS exposure of a group of restoration stoneworkers and to investigate the implication of this study for the wider stoneworker community in Ireland. Results from the exposure assessment study were used to design and execute a workplace intervention comprising of technical and worker elements to reduce worker exposure to RCS. An auxiliary element of this study will involve investigating the performance of high flow rate samplers for the collection of low concentrations of RCS under restoration stone work field conditions.

2.0 Overview of chapter

This chapter presents an overview of the literature relevant to this study and is discussed under the following themes: respirable crystalline silica (Section 2.1); health effects of occupational exposure to RCS (Section 2.2); occupational exposure to RCS (Section 2.3); workplace interventions to reduce occupational exposure to RCS (Section 2.4); research needs in the area of occupational exposure to RCS (Section 2.5) and objectives of research project (Section 2.6).

2.1 Respirable crystalline silica

Silica (silicon dioxide, SiO_2) is found in the earth's crust and occurs in both crystalline and non-crystalline forms. The most common forms of crystalline silica are quartz, cristobalite and tridymite. Cristobalite and tridymite are found naturally in meteorites and volcanic rocks, or form artificially at temperatures of over 450^{o}C for example, in industrial furnaces and kilns during the production of refractory materials. Quartz is present in almost all types of rock, sands, clays, shales and gravel for example; sandstone contains 33% - 90% quartz with an average quartz content of 82% (% weight/weight) or higher whereas limestone contains < 2% quartz (Carmichael, 1989; Pavia and Bolton, 2000; Kissane and Pavia, 2008). Concrete and rubble contain varying amounts of quartz (≈10% - 70%) depending on the quartz content of the aggregate which makes up 60-75% of the volume of concrete (Linch, 2002). When these materials are processed through work activities such as grinding and cutting for example, particulate, containing varying quantities of respirable crystalline silica is released into the occupational environment.

Airborne stone dust contains particles of various sizes which reach different parts of the lung depending on their aerodynamic diameter. In the occupational environment, aerosols are defined by three health related aerosol fractions – inhalable, thoracic and respirable fractions. The respirable fraction is defined as the mass fraction of particles that reach the alveoli and have a median aerodynamic* value of 4.25 μm with a GSD of 1.5 μm (BS EN481, 1993).

*The aerodynamic diameter is the diameter of a hypothetical sphere of density 1 g/cm3 having the same terminal settling velocity in calm air as the particle in question, regardless of its geometric size, shape and true density (WHO, 1999).

The typical particle size of crystalline silica is 7 μm (Seaton, 2012) and is particularly harmful because of its potential to damage the alveolar region of the lung. It is this fraction of crystalline silica dust which is associated with long term health problems (HSA, 2010). Figure 1 illustrates crushed quartz particles as seen under a microscope.

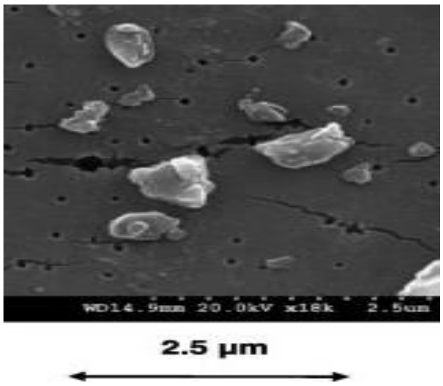


Figure 1: Detailed microscopic view of crushed quartz particles (Huffman *et al.*, 2012).

2.2 Health effects of occupational exposure to respirable crystalline silica.

Respirable crystalline silica is associated with a wide range of adverse health effects. The most widely reported ill health effect associated with exposure to silica is silicosis (Hodel, 1977; Landrigan *et al.*, 1986; Swaen *et al.*, 1988; Prowse K *et al.*, 1989; Saiyed *et al.*, 1995; Robinson *et al.*, 1995; Starzynski Z *et al.*, 1996; Rosenman *et al.*, 1996; Forastiere *et al.*, 2002), however exposure to respirable crystalline silica is also associated with a range of other adverse health effects for example lung cancer (Siemiatycki *et al.*, 1989; IARC 1997; Steenland and Ward, 2014), stomach cancer (Siemiatycki *et al.*, 1989), a range of autoimmune diseases such as systemic sclerosis (Creamer *et al.*, 1985; Englert *et al.*, 2000), rheumatoid arthritis (Stolt *et al.*, 2005), chronic renal disease (Steenland *et al.*, 1990, 1992, 1995), subclinical renal disease (Hotz *et al.*, 1995) and cardiovascular disease (Chen *et al.*, 2012). There is also evidence that workers exposed to silica are at an increased risk of tuberculosis even in the absence of radiographic evidence for silicosis (Levy and Wegman, 2010), other mycobacterial infections of the lungs (Corbett *et al.*, 1999) and chronic obstructive pulmonary disease (COPD) (Oxman *et al.*, 1993).

Silicosis is a well-known fibrogenic lung disease, probably one of the most ancient occupational illnesses (WHO, 2007) and efforts to prevent silicosis have a long history. The first international conference on silicosis was convened by the International Labour Organisation (ILO) in August 1930 in Johannesburg, South Africa and focused on the prevention of silicosis, which was highly prevalent in miners at that time. Although the prevalence of silicosis has decreased in the U.S and in Europe (WHO, 2007), silicosis still occurs in many sectors including; mining (Hnizdo and Sluis, 1998; De Klerk, 1998; Kress, 1996; Cauda *et al.*, 2012; Pretorius, 2012) foundry (Landrigan *et al.*, 1986; Starzynski Z *et al.*, 1996; Rosenman *et al.*, 1996) pottery (Swaen *et al.*, 1988; Prowse K *et al.*, 1989; Saiyed *et al.*, 1995; Forastiere *et al.*, 2002) stone masonry (Rodriguez *et al.*, 2012) and construction (Robinson *et al.*,1995). High risk activities such as sandblasting (CDC, 1990) and concrete drilling (Hodel, 1977) also have well-documented associations with silicosis.

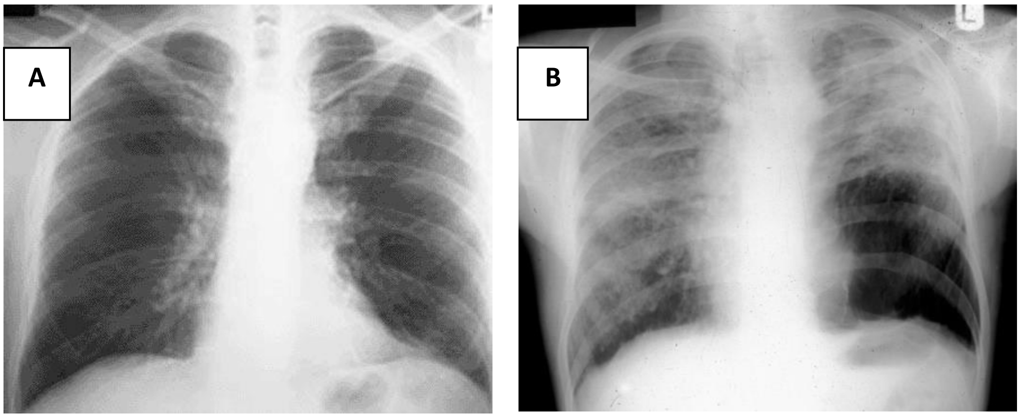
Silicosis occurs when RCS dust is deposited in the respiratory system, which leads to the thickening and fibrosis of the lungs. Silicosis occurs more frequently in the upper lobe of the lung, with silicotic nodules varying in size from invisible to 6 mm in diameter. In some cases, nodules may aggregate and become fibrotic masses. Unfortunately fibrosis of the lung often progresses even after removal from exposure and symptoms may not appear for many years (Levy and Wegman, 1995). Regulatory agencies such as the Health and Safety Executive UK, predict a 20% risk of developing silicosis with an average daily exposure of 0.3 mg/m^3 over 15 year period (HSE, 2005). The progression of the disease can be categorised as chronic, accelerated or acute silicosis;

- Chronic silicosis develops slowly after exposure to relatively low concentrations (0.05 mg/m^3- 0.1 mg/m^3) of crystalline silica over 20 – 45 years (Greaves, 2000). Chronic silicosis is classified as either simple or complicated. When the silicotic nodules are discrete, the condition is termed simple and be diagnosed readily from chest x-ray after at least 10 years of exposure. Complicated silicosis is also referred to as progressive massive fibrosis (PMF), where several of the simple nodules conglomerate to produce larger nodules which encroach on the airways.
- Accelerated silicosis develops more rapidly, within 5 to 10 years of exposure to approximately concentrations < 1 mg/m^3 (Seaton, 2012). Accelerated

silicosis differs from chronic silicosis by its more rapid course (Bope and Kellerman, 2012).

- Acute silicosis occurs within two or three years of exposure to levels approximately > 1 mg/m^3 (Seaton, 2012) (Figure 2b), leading to symptoms within a few weeks to a few years after exposure (Duffus and Worth 2006; Bope and Kellerman, 2012). The pathology of acute silicosis shows a wide spread fibrosis; with diffuse interstitial rather than nodular macroscopic appearance. It is often fatal, generally within 1 year (McCunney, 1988).

  Acute silicosis and accelerated silicosis are rather arbitrary terms describing pathological and radiological manifestations and their diagnosis depend, inter alia, on whether there has been sufficient prior exposure to destroy the hilar lymph nodes and thus prevent removal of the quartz (Seaton, 2012).



Figures 2: Chest X-ray of patient with healthy lung (A) vs. patient with acute silicosis (B) (Guthrie, 2012; Seaton, 2012)

The variability in the fibrogenic potency (i.e. ability to cause silicosis) of RCS dust can depend on many factors within the occupational environment for example; the toxicity of RCS dust is greater when produced from freshly formed surfaces as compared with dusts from "aged" surfaces and is also influenced by particle size, small particles are more toxic, due to increased surface area, for example in the case of silica flours, (HSE, 2002).

There has been extensive debate on the carcinogenicity of crystalline silica since the International Agency for Research on Cancer (IARC) classified RCS as a Group 1 carcinogen in 1997 (McDonald, 1989; Pairon *et al.*,1991; Weill and McDonald, 1996; Soutar *et al.,* 2000; Checkoway, 2000; Hessel, 2000). In making their decision, the

IARC working group reviewed over 500 relevant scientific publications and concluded that there was "sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica in the form of quartz or cristobalite from occupational sources'' (Costello and Graham, 1988; Puntoni *et al*., 1988; Merlo *et al.*, 1991; Costello *et al.*, 1995; Cherry *et al.*, 1995, 1997; Steenland and Brown, 1995; McDonald *et al*., 1997; Burgess *et al*., 1997). Later in 2009, the IARC working group convened in Lyon to reassess the monographs on silica and revised their decision, concluding that the classification of silica as a carcinogen was justified (IARC, 2012). This decision was based on the review of studies published post 1997 (Hessel *et al.*, 2000; Chen *et al.*, 2001.; Rando *et al.*, 2001; McDonald *et al.*, 2001; Steenland and Sanderson, 2001; Kurihara and Wada 2004; Pelucchi *et al.*, 2006) and focused on studies with exposure-response (E-R) analysis because they provide stronger evidence of causation and facilitate accurate assessment of exposure-response in the presence of confounder variables (Gamble, 2011).

Several studies support the association between occupational exposure to RCS and lung cancer in Finland (Koskela *et al.*, 1994), Denmark (Guénel *et al.*, 1989) and the U.S (Davies *et al.*, 1973; Attfield and Costelloe, 2004). The research that provides the most convincing evidence of carcinogenicity indicates that increased risks of lung cancer are restricted to those groups with the highest cumulative exposures to respirable crystalline silica dust. The groups with the highest cumulative exposures tend to be the first hired workers who commenced employment before the introduction of adequate dust controls (Costello and Graham, 1988; Checkoway *et al.*, 1997; Hughes *et al.*, 2001; Steenland and Sanderson, 2001).

The debate on the carcinogenicity of crystalline silica still exists due to conflicting evidence in the literature of the relationship between exposure to silica and development of lung cancer. Some (Gamble, 2011) are opposed to the IARC Group 1 carcinogen classification because carcinogenicity in humans was not detected in all industrial circumstances reviewed by the working group and most studies were limited in some respect. Others do not support the notion that an increased risk of lung cancer is restricted to groups with the highest cumulative exposures (Davies *et al.*, 1973; Steenland and Brown, 1995; Reid and Sluis-Cremer, 1996; Cherry *et al.*, 1998). Some of the studies reviewed by IARC showed a positive significant relationship between silica exposure and lung cancer risk and/or between silicosis and lung cancer risk, but other studies indicated no significant association. Furthermore, few of the published studies that were reviewed by IARC in 1997 included a quantitative exposure-response (E-R) analysis, which provide the strongest evidence of causality and can be a basis for standard setting (Mannetje *et al.*, 2002). The IARC working group's conclusion in 1997 was preceded by the following paragraph: 'In making the overall evaluation, the working group noted that carcinogenicity in humans was not detected in all industrial circumstances studied. Carcinogenicity may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs' (IARC, 1997). This unusual provision illustrates well the essential difference between the concepts of hazard, which was considered as justified and risk, which would clearly have required considerably more descriptive and quantitative evidence (McDonald, 2000). The IARC working group did focus on E-R studies when revising their decision in 2009 but some (Gamble, 2011) when reviewing the same studies found weak associations and lack of E-R trends that did not support a causal association of lung cancer and silica exposure. Gamble, 2011 concluded that the weight of evidence from occupational epidemiology does not support a causal association of lung cancer and silica exposure, which is contrary to the IARC conclusion using essentially the same data.

The National Institute for Occupational Safety and Health recommend that RCS be considered a potential occupational carcinogen (NIOSH, 2002), the National Toxicology Program of the National Institute of Environmental Health Sciences have concluded that RCS is known to be a human carcinogen (NT Program, 2012) and the Scientific Committee on Occupational Exposure Limit Values SCOEL have also made the recommendation that the relative risk of lung cancer is increased in persons with silicosis.

In the Employment, Social Affairs and Equal Opportunities department of the European Commission, RCS has received much attention due to the fact that it is classified as an IARC Group 1 carcinogen and internationally it is recommended that the OELV for RCS is reduced. Respirable crystalline silica remains unclassified as a carcinogen in many EU states including Ireland and under Australian and South African legislation but some EU countries such as the Netherlands and Denmark have classified RCS as a carcinogen.

The Irish Health and Safety Authority have set an 8 hr TWA occupational exposure limit value (OELV) of 0.1mg/m^3 in their 2011 Code of Practice for the Safety, Health and Welfare at Work Act (Chemical Agents) Regulations 2001. Internationally the recommended OELV for respirable crystalline silica continues to be lowered as a result of improvements in understanding of the health effects associated with RCS exposure. Possible introduction of a binding OELV for RCS through the European Chemical Agents Directive (1998/24/EC) or inclusion of RCS as part of Annex I of the European Carcinogens Directive (2004/37/EC) is important because a designation of carcinogenicity would likely result in a lower OELV for RCS being adopted in the workplace. The European Scientific Committee for Occupational Exposure Limits (SCOEL) recommended that, to eliminate silicosis, European occupational exposure standards should be set below 0.05 mg/m^3. Other studies also indicate a reduced risk to worker health at lower concentrations (NIOSH 2002; HSC, 2005). This has increased the pressure on legislative authorities to reduce exposure limits to a level where research suggests that the risk of damage to the health of an individual is minimal.

In 2006, 16 industry sectors which handle silica (The European Network on Silica (NEPSI)), signed a European multi-sectorial social dialogue agreement "Agreement on Workers Health Protection through the Good Handling and Use of Crystalline Silica and Products containing it*"*. The primary aim of the agreement is to minimise exposure to respirable crystalline silica at work through the application of good practices and requires signatories to monitor airborne dust and health, provides for central collection of data on workplace exposures and work practices and contains guidance documents on the control of silica (NEPSI, 2013). Another EU-wide agreement on the control of silica in the workplace is the Dust Monitoring Program run by the European Industrial Minerals Association (IMA-Europe) which allows participating companies to receive regular information on their respirable dust and RCS exposure levels, identify areas of high exposure risk and monitor effectiveness of exposure controls implemented (IMA-Europe, 2012). Results of the program indicate that there has been a two to three fold reduction of exposure concentrations since the start of this project around the year 2000 (Kromhout *et al.*, 2013). One view argues however, that the industry-initiated negotiations were mainly a bid to avoid a community wide reduction in the OELV for RCS and community recognition of RCS as being a human carcinogen (Musu and Sappair, 2006). In May 2012, the social dialogue signatories met to discuss their position regarding the discussion on a possible inclusion of Respirable Crystalline Silica (RCS) in the Carcinogens Directive to the European Commission and its Committees. They concluded that the European

Carcinogens Directive is not the suitable regulatory solution for RCS and that the best regulatory solution would be to include a Binding European OELV of 0.1 mg/m^3 in the Chemical Agents Directive.

2.3 Review of RCS occupational exposure studies

Sources of occupational exposure to silica dust are diverse and include the mining and processing of silica-containing rock as well as the manufacturing and construction processes that use silica as a tool or raw material. Silica sand and gravel are used in road construction and in the manufacture of concrete, glass and ceramics, foundry castings, and abrasives such as sandpaper and sandblasting materials. Silica sand or flour is used as filler in detergents, paints, plastics, and cements; as a filtering agent for water, sewage, and food production; and as the primary component of some abrasive cleansers (Parks *et al.*, 1999).

A European study on occupational exposure to carcinogens in fifteen EU member states (CAREX) between the years 1990-1993 estimated that 3.2 million were exposed at least 75% of their working time to crystalline silica. Occupational exposure to silica in the CAREX database was defined as exposure (exceeding non occupational exposures i.e. from road dust, beach sand etc (≈<0.01 mg/m^3) at work to crystalline silica or minerals containing crystalline silica by inhalation (CAREX, 1999). These estimates were adjusted for the economic structure (workforce distribution) of each country individually but did not take into account country-specific exposure patterns which may deviate from those of the reference countries, Finland and the US (Kauppinen *et al.,* 1998). This study estimated that approximately 29,000 workers in Ireland were exposed to RCS at least 75% of their working time (Kauppinen *et al.,* 2000). The Irish estimates were default (preliminary) estimates generated by the CAREX system. A report compiled by the Institute of Occupational Medicine in 2011, estimated that approximately 5.3 million employees in the EU are exposed to RCS and that about 4 million of these are in the construction industry (Cherrie *et al.*, 2011).

Workplace exposure to respirable crystalline silica is well documented in many industries including; construction (Pannell and Grogin, 2000; Lumens and Spee, 2001; Tjoe Nij *et al.*, 2003; Heitbrink, 2006; Garcia *et al.*, 2006; Echt *et al.*, 2007; Middaugh *et al.*, 2012), construction/roofing manufacture (Fayerweather *et al.*, 2011; Hall *et al.,* 2013), the heavy clay industry (Love *et al.*, 1999), potteries (Cherry *et al.*, 1998), the industrial silica sand industry (Brown and Rushton, 2005), agriculture (Archer *et al.*, 2002; Swanepoel *et al.*, 2011a, 2011b; 2013), abrasive blasting and stone cutting (Mohammadyan *et al.,* 2013; Radnoff and Kutz, 2014） exploration of natural resources (hydraulic fracking) (Napoli, 2012; Esswein *et al.*, 2013) and in stonemasonry (Seaton and Cherrie, 1998; Guénel *et al.*, 1989; Tharr and Lofgren, 1993; Attfield and Costelloe, 2004; Cain, 2009; HSE, 2009). Highest RCS exposures (0.04 to 1.21 mg^3) have been recorded for roofers (Garcia *et al.*, 2006), followed by tuckpointing (0.79 to 1.1 mg/m^3) (Echt *et al*., 2007), heavy clay industry (0.04 to 0.6 $mg.m^3$) (Love *et al.*, 1999) and granite top fabrication (<0.04 to 0.58 mg/m^3) (Simcox *et al.*, 1999). Lower exposures have been recorded within the pottery sector (0.05 - 0.2 mg/m^3) (Cherry *et al.*, 1998) and in the industrial sand sector (geometric mean RCS concentration of 0.09 mg/m^3) (Brown and Rushton, 2005). A study in the U.S found that some of the highest respirable crystalline silica dust concentrations occurred in construction (masonry, heavy construction, and painting), followed by iron and steel foundries (casting), and in metal services (sandblasting, grinding or buffing of metal parts). It was found that 1.8% (n = 13,800) of the workers in the standard industrial classification (SIC) group number 174—Masonry, Stonework, Tile Setting, and Plastering were exposed to at least 10 times the NIOSH REL of 0.05mg/m^3 (Linch *et al.*, 1998).

A number of studies have been conducted on respirable crystalline silica exposure among stoneworkers outside of the construction sector (Davies *et al.*, 1973; Guénel *et al.*, 1989; Tharr and Lofgren, 1993; Koskela *et al.*, 1994; Seaton and Cherrie, 1998; Attfield and Costelloe, 2004; HSE 2009; Cain, 2009) but few have studied respirable crystalline silica exposure amongst stoneworkers involved in monument restoration work (Davies *et al.*, 1973; Seaton and Cherrie, 1998; HSE, 2009) or those working with high silica materials such as sandstone (Seaton and Cherrie, 1998; Tjoe Nij *et al.*, 2003; HSE, 2009).

Sandstone was widely used down through the centuries, in the construction of domestic and public buildings, sculptures and monuments across Europe. In the U.K, sandstone was used for house building in many of the towns and cities in the north, north east and midlands of England as well as for civic buildings, factories, mills and engineering projects such as railway bridges, viaducts and reservoirs. (Dimes and Mitchell 2006). In the 18^{th} to 19th century the local sandstones supplied the majority of buildings constructed in the New and Old Towns of Edinburgh (now a World Heritage Site). The City of Glasgow also contains many buildings constructed from locally available Carboniferous sandstone. In Ireland, sandstone was used in the construction of many pre and post Christian sites such as Newgrange, the 6th century cross of the scriptures at Clonmacnoise and the 8th century high crosses at Ahenny, the cross of Muiredach in Monasterboice from the 10th century, the Cistercian Abbey in Boyle from the 12th century and 13th century monuments such as the Rock of Cashel (World heritage site), Nenagh castle, the main guard in Clonmel and St. Brendan's Cathedral at Clonfert.

In recent years, there has been a move to use traditional craft skills and traditional materials to repair restore and conserve historic building fabrics in Ireland (Bolton, 2006) and sandstone is used regularly amongst the restoration stonemasons and stonecutters responsible for the conservation of Ireland's monuments. Research has been conducted on the techniques involved in the restoration of sandstone monuments in Ireland and Scotland (Ingval, 1996; Kamh, 2005; Bolton, 2006; Kissane and Pavia, 2008; Young *et al.*, 2003) but little research has been conducted on the occupational exposure of the workers involved in this restoration work (Davies *et al.*, 1973; Seaton and Cherrie, 1998; HSE, 2009). Sandstone is a sedimentary rock with average quartz content of 82% by weight (Carmichael, 1989). The quartz content of some sandstone samples used in the conservation of Irish monuments ranges from 50% - 85% (Kissane and Pavia, 2008). Respirable crystalline silica levels are related to the crystalline silica content of the rock being worked (Guénel *et al.*, 1989a; Kullman *et al.*, 1995) which means stoneworkers involved in the cutting and grinding of sandstone, can be exposed to excessive levels of respirable dust containing crystalline silica.

Data on recognised occupational diseases in the EU 12 member states was collected for the reference year 2001 (Karjalainen and Niederlaender, 2004). There were 497 new cases of silicosis diagnosed in 2001. Only six member states could provide data on fatal cases of occupational disease, in these six states, silicosis was the fifth most common fatal occupational disease with 50 deaths due to silicosis confirmed (Karjalainen and Niederlaender, 2004).

Occupationally-related cases of respiratory disease related to silica exposures have been reported to three occupational health reporting networks in the U.K and Ireland. The Health and Occupation Reporting Network (THOR) is a network of physician led voluntary surveillance schemes to monitor the incidence and determinants of occupational disease and work-related ill-health, operating in the UK since 1989 and in Ireland since 2005. The Surveillance of Work-related and Occupational Respiratory Disease (SWORD) reporting network was set up specifically for respiratory physicians to monitor the incidence of work-related respiratory diseases, operating in the UK since 1988 and in Ireland since 2005. The Occupational Physicians Reporting Activity (OPRA) is specifically for occupational physicians to report cases of disease or illness caused by work which has been in operation in the UK and Ireland since 1996 and 2007 respectively. It is important to note that silicosis may be misclassified as another lung disease e.g. chronic obstructive pulmonary disease (COPD), tuberculosis, lung cancer or cardiovascular diseases (Goodwin *et al*., 2003) and for this reason, cases of silicosis may be vastly underreported. According to a report by the HSE on occupational cancer in Britain, there is an underreporting of cases of silicosis in the UK (HSE, 2010).

In the UK, between the years 1989 to 2005, 747 estimated cases of respiratory disease attributed to silica were reported by chest physicians to SWORD and 27 estimated cases were reported to OPRA. Of the cases reported to SWORD, there were 32 actual cases of pneumoconiosis and 2 actual cases of lung cancer among stonemasons (HSE, 2009).

There have been eight cases of work-related pneumoconiosis attributed to silica reported by chest physicians to SWORD ROI (2005-2011). All cases were reported in males with an age range of 47-74 years. Six of these cases were reported in the mining industry. The other two cases were reported in the manufacture of rubber industry and a foundry worker. Five of these cases had occupations reported as retired tuneller, the remaining occupations were specified as miner, sandblaster and factory worker. There have been no cases of work related silicosis or work related pneumoconiosis attributed to silica reported by occupational physicians to OPRA ROI (2007-2011) (Money, 2012). Reporting to all the THOR schemes is entirely voluntary, and therefore subject to bias from under-reporting. The THOR, SWORD and OPRA reporting networks in Ireland were only established in 2005 and 2007 respectively and a comparatively smaller number of Irish chest physicians report to SWORD than in the UK. Also, in many industries few, or even no sufferers, will have access to an occupational physician, which means that incidence rates based on or including OPRA reports cannot be used as a fair basis of comparisons between industries or occupations which have different degrees of coverage by such doctors.

2.4 Workplace interventions to reduce occupational exposure to respirable crystalline silica

2.4.1 Review of RCS technical intervention studies

When an occupation has an unacceptable probability of over exposure, some form(s) of intervention is required. Health and safety professionals use a hierarchy of controls when selecting the appropriate methods for preventing or minimising workplace hazards. In the case of reducing exposure to RCS during the restoration of historic monuments, the elimination or substitution of sandstone is not feasible as it is a requirement to use the traditional material. The implementation of engineering controls for example local exhaust ventilation in the workplace to reduce exposure to dust is otherwise known as a technical intervention. An ‘intervention’ can be defined as an attempt to change how things are done in order to make an improvement (Robson *et al.,* 2001) for example introducing local exhaust ventilation for a concrete cutting tool in order to reduce airborne dust (Shepard and Woskie, 2010). Technical interventions have been implemented in many occupational settings to address various occupational hazards including nicotine amongst tobacco harvesters (Ghosh *et al*., 1991), chemicals amongst hospital workers (Kercher and Mortimer, 1987), concrete dust (Shepard and Woskie, 2010) and lower back pain (Hess *et al.,* 2004) among construction workers.

It has been well documented that workers involved in the cutting, drilling and grinding of silica containing materials are exposed to excessive levels of respirable crystalline silica dust (Hallen, 1983; Chrisholm, 1999; Linch, 1997, 1998, 2002; Lumens and Spee 2001; Akbar-Khanzadeh and Brillhart, 2002; Rappaport *et al.*, 2003; Tjoe Nij *et al.*, 2003; Flanagan *et al.*, 2003, 2006; Echt *et al.*, 2007; HSE, 2009; Healy *et al.*, 2014) across construction, restoration and monumental stone trades. It has also been found that there is a risk of exposure to others workers in the area as well as the worker carrying out the task (Woskie *et al.,* 2002). Numerous studies have identified the grinding (Croteau *et al.*, 2002; Akbar-Khanzadeh and Brillhart, 2002; Flanagan *et al.*, 2003, 2006; HSE, 2009; Healy *et al.*, 2014) and cutting (Tjoe Nij *et al.*, 2003; Meeker *et al.*, 2009) as creating overexposure to silica dust. A number of research studies have evaluated the effectiveness of various local exhaust ventilation (LEV) designs, commonly known as shrouds for grinding concrete (Echt and Sieber, 2002; Akbar-

Khanzadeh and Brillhart, 2002; Flanagan *et al.*, 2003; Croteau *et al.*, 2004; Akbar-Khanzadeh *et al.*, 2007, 2010; HSE, 2012) and cutting concrete (Thorpe *et al.*, 1999; Echt *et al.*, 2007; Meeker *et al.*, 2009; Sheperd *et al.*, 2009). The materials being worked on in these studies typically contained silica content of < 50% for example cellular concrete blocks containing 24 – 54% silica (NIOSH, 2007) and paving slabs containing 12 - 40% silica (Thorpe, 1999). These studies have shown that with respect to grinding concrete, the use of a shroud has shown to reduce respirable crystalline silica dust exposures by 95% (Croteau *et al.*, 2002), 92% (Croteau *et al.*, 2004), 95% (Echt, *et al.*, 2007) and 98% (Akbar-Khanzadeh *et al.*, 2010). Similar studies examining the effect of shrouds on reducing RCS exposure from cutting tools found a reduction of 90% (Thorpe *et al.*, 1999) and 80% (Sheperd *et al.*, 2009). For many stonemasonry activities which use power tools such as angle grinders, local exhaust ventilation appears to be the most effective and practical method for reducing silica dust exposures (Croteau *et al.*, 2004). Few studies have investigated respirable dust and RCS concentrations associated with shrouds outside of the construction sector, and when working with a material other than concrete (Tjoe NiJ *et al.*, 2003). Tjoe NiJ *et al.*, 2003 found that the application of a shroud reduced respirable dust levels by > 99% when cutting sandstone.

Restoration stoneworkers can be distinguished from other stone work groups, such as construction, by their regular use of different grinding tools and grinding wheels unique to the trade. For this reason, exposure controls marketed towards, and suitable for stone masonry in other sectors, may not be suitable for restoration stone work. Decorative stone work carried out by a restoration stoneworker, is often more detailed and precise, than that of a construction stone mason, requiring the worker to position themselves close to the work, and dust source. Restoration stoneworkers are often required to adhere to conservational guidelines and to work with traditional materials and techniques. For this reason, the elimination or substitution of high silica content materials, for example sandstone or granite is not an option. Sandstone is a naturally occurring material, regularly used by restoration stone masons, with a quartz content of between 52% - 90%. Sandstone not only has a framework consisting of predominantly quartz grains but is also often bound together by a quartz rich cementing agent (Pettijohn, Potter and Siever, 1987; McBride, 1985). Previous studies have shown that there is a high reliance on respiratory protective equipment (RPE) in stone masonry (HSE, 2009; Healy *et al.,* 2013, 2014), which further prioritises further investigations into the use of engineering controls for this sector.

The higher quartz content and unique composition of sandstone could potentially influence the effectiveness of a shroud, designed to reduce worker and bystander exposure to respirable dust. Many local exhaust ventilation shrouds are marketed towards a wide range of tasks and workers for example grinding, cutting, and sanding concrete (< 50% quartz), masonry surfaces and other materials (Dustless Technologies, 2013) and grinding fiberglass, concrete, wood, paints and epoxies (Dust Collection Products, 2013). Products marketed towards construction workers may not be practical for use by restoration stonemasons as their work is much finer and more precise than that of construction workers. This difference in use, may also affect the shroud's performance and its feasibility in this occupation. Developing effective engineering controls for tasks involving angle grinders and high silica containing materials is important in occupations such as restoration stonemasonry where the elimination and substitution of high silica containing materials such as sandstone is not an option.

2.4.2 Review of worker intervention studies

For an engineering control such as local exhaust ventilation to be an effective intervention, it not only has to remove dust but it must also be used regularly, maintained and become part of a normal work process (Shepherd *et al.*, 2010). When applying the hierarchy of controls, important individual and environmental factors that affect the long-term success of an intervention are often overlooked (Brosseau *et al*., 2002). Effective risk control depends in part on the behaviour of individuals at all levels within an organisation not just the implementation of engineering controls for example on their own and a well-designed workplace intervention should integrate organisational and psychosocial elements as well as technical measures. (Goldenhar *et al*., 2001; HSE, 2002; Seixas *et al*., 2011). When implementing a workplace intervention, it is important for the workers themselves to have knowledge of the hazard (Lahiri *et al.,* 2005). Taking psychosocial and organisational factors such as safety knowledge, attitudes and behaviour and safety culture into account in order to reduce worker exposure to an occupational hazard is called a human or worker intervention.

Research has been conducted on some of the factors that form a human intervention. Studies which have investigated attitudes and behaviours of workers related to the use and non-use of personal protective equipment (PPE) and the barriers of use of PPE have focused primarily on respiratory protective equipment (RPE) (Laird *et al*.,1993; Akar-Khanzadeh *et al.,* 1995; Salazar *et al*., 1999; Mitchell and Schenker, 2008; Radonovich *et al.,* 2009; Daugherty *et al.,* 2009; HSE, 2009; Baig *et al.,* 2010; Fukakusa *et al.*, 2011) and other PPE such as gloves, protective eye wear, hard hats and coveralls (Linn *et al.*, 1990; Helfgott *et al.,* 1998; Carpenter *et al*., 2002; Ganczak and Szcyh, 2007; MacFarlane *et al.,* 2008). The majority of these studies have been carried out in the health care sector with only a few (White *et al.*, 1989; Laird *et al.*, 1993; Akbar-Khanzadeh *et al.,* 1995; Salazar *et al.,* 1999) conducted amongst industrial workers and one in the stonemasonry sector (HSE, 2009). The most common factors influencing a workers use of the recommended RPE assigned for a task was physiological reasons including difficulty breathing during manual tasks, shortness of breath, straps cutting into the ear, lack of vision, difficulty communicating with co-workers, difficulty communicating with patients and finding full face masks heavy and cumbersome (White *et al.*, 1989; Laird *et al.*, 1993; Lange *et al.*, 1996; Akbar-Kahnazadeh, 1995, 1998; Salazar *et al.*, 1999; Radonovich *et al.,* 2009; HSE, 2009; Baig *et al.,* 2010; Fukakusa, 2011). Other factors influencing RPE usage included personal factors such as smoking, low self-assessment of health status (Donham *et al.*, 2013) and time constraints and inconvenience (Helfgott, 1998). Results reported by Salazar *et al.*, 1999 indicate workers categorised as labourers were more likely to be frequent respirator users and to wear air supplied respirators than other worker groups such as engineers and managers and that the most common factors for employees not using the recommended RPE fell into four categories believed to affect employee use of exposure controls. These categories were: employee knowledge, beliefs and attitudes, physical and physiological effects and external influences. This study found that the most common factors for employees not using the recommended RPE fell into all four of these categories. Within the knowledge and belief category, the principal reasons for employee's non-use of RPE included employee perception that the task was not hazardous. Similar findings were also reported by Lange *et al.*, 1996; Vaughan *et al.,* 1993; Mitchell *et al.*, 2008 and Mitchell and Schenker, 2008. Little research has been conducted on the attitudes and behaviours of workers related to the use and non-use of engineering controls such as shrouds (Lazovich *et al*., 2002; Thompson and Wake, 2007). The factors which influence a worker to use or not use an exposure control could potentially assist or impede the implementation of a technical intervention. The attitude of the workers as well as external influences, both need to be investigated when implementing an intervention to reduce health hazards associated from silica dust exposures. Shepherd *et al.*, 2010 carried out a study on the implementation of a shroud for a concrete grinder, examining the roles that various members of the construction team played. The results showed that a multifaceted approach must be taken when implementing new technology in construction. It was found that the intervention must be accepted by safety personnel and the availability of an engineer that had ability to make technical improvements to make control work was an important contribution. This study also concluded that the equipment must provide good results and the end users must be consulted to understand the practical requirements of the control. Graveling *et al.*, 2011 also found that there were benefits of an inclusive organisational culture. It was found that where employees are more actively involved in the risk reduction process, they were more likely to sign up to the eventual solution.

2.5 Research needs in the area of occupational exposure to respirable crystalline silica

Despite respiratory illnesses associated with stone work being recognised since the beginning of the 18th century (Ramazzini, 1940), high levels of exposure to RCS are still regularly encountered in many occupational groups (Love *et al.*, 1999; Simcox *et al.*, 1999; Croteau *et al.*, 2002; Akbar-Khanzadeh and Brillhart, 2002; Garcia *et al.*, 2006; Flanagan *et al.*, 2006, 2003; Echt *et al*., 2007; HSE, 2009). Also, despite the SCOEL recommendation since 2003 to control RCS to a level of 0.05 mg/m^3 and the IARC classification of RCS as a group 1 carcinogen since 2007, there remains no binding OEL or carcinogen classification in the EU for RCS. Thus, in Europe, discussions are currently in progress in the European Commission's Advisory Committee on Safety and Health at Work (ACSHW, 2012; IBEC, 2012) and worker's interest groups (European industry sectors which handle silica (IMA *et al*., 2012), European Federation of Building and Woodworkers (EFBWW, 2012), European Association for Coal and Lignite (EURACOAL, 2012)) on the inclusion of RCS in Annex I of the European Carcinogens Directive. Debate on the introduction of a binding OEL for RCS through Annex III of the European Carcinogens Directive or the European Chemical Agents Directive is also on going. In 2009, the Institute of Occupational Medicine carried out a study on the socioeconomic, health and environmental impact of possible amendments to the European Carcinogens and Mutagens Directive (SHEcan). Respirable crystalline silica was included in this study and was investigated in two work packages; work package 8 'Assess the impact of introducing four additional substances onto the list contained in Annex I of the Directive' and work package 10 'Assess the impact of introducing OELs for 20 substances'. This report established that if the OEL for RCS was reduced to 0.05 mg/m^3, by 2060, the number of lung cancer registrations attributable to RCS exposure would be reduced to < 100 and that the total net health benefits would range from €28,000m to €74,000m. All things considered, it was concluded that in monetary terms, the health benefits of introducing an OEL would outweigh the cost of compliance and that there is a strong case for reducing the OEL for RCS (Cherrie *et al.*, 2011). This opinion was also adopted in 2012 by the European Advisory Committee for Safety and Health at Work (ACSH) who were in favour of adding a new occupational exposure limit (OEL) for RCS to a revised Carcinogens Directive (ACSHW, 2012).

Since the EU is in the process of considering an update to the Carcinogens Directive which includes a discussion about introducing a binding OEL for RCS, this provides a powerful stimulus to control RCS exposures and to carry out additional exposure assessments to further examine the effect exposure determinants may have on worker RCS exposure and for controlling exposure to RCS.

2.5.1 RCS analytical and measurement challenges

In order to support enforcement activity, one needs to be able to measure and analyse the contaminant of interest with accuracy and confidence at the assigned OEL. An issue with enforcing an exposure limit of less than 0.1 mg/m^3 RCS, relates to the sensitivity of the current analytical techniques, x-ray diffraction (XRD) (HSE, 2005; NIOSH, 2003a) and infrared analysis (IR) (NIOSH, 2003b). As explained by Stacey in 2007 (Stacey, 2007), the theoretical limit of detection (LOD) of the analytical techniques (5 to 10 µg per sample, equivalent to 0.005 to 0.01mg/m^3 for an 8-h sample collected at 2.2 l/min) is difficult to achieve in real samples because of issues such as sampling times less than 8 hours, measurement precision, interferences in the sample, and reliable calibration standards. Using commonly employed respirable aerosol sample collectors operating at 1.7 to 2.2 l/min, it will therefore be difficult to demonstrate compliance with a reduced occupational exposure limit (OEL) of less than 0.1 mg/m^3, especially when measuring work tasks lasting less than 8 hours. Several studies have investigated the measurement of (Stacey and Thorpe, 2009; Eypert-Blaison *et al.*, 2011; Lee *et al.*, 2012, 2010; Verpaele and Jouret, 2013) and analysis of (HSE, 2002; Virji *et al.*, 2002; Stacey, 2006) low concentrations of airborne RCS. Increasing the sample mass collected for RCS analysis by adopting high-flow samplers is seen as the most probable way to remediate the difficulties of measuring very low levels of RCS in the workplace. It is hoped that these samplers may be able to collect sufficient mass of respirable dust for subsequent crystalline silica analysis even for samples of less than 8 hours. Commercially available high-flow-rate samplers include the CIP10-R (Gero and Tomb, 1988), the GK2.69 cyclone (Kenny and Gussman, 1997) and the FSP10 cyclone (Dahmann *et al.*, 2001). The feasibility of using these commercially available high-flow samplers to increase the sample mass collected and improve the reliability of RCS measurement at low RCS concentrations has been evaluated in laboratory studies (Stacey and Thorpe, 2009; Lee *et al.*, 2012, 2010) but few (Stacey and Thorpe, 2009; NIOSH, 2010) have evaluated high-flow samplers in real occupational environments. Such studies are required in order to assess the samplers' practical use in the field and to validate results from laboratory studies. Restoration stoneworkers regularly work with low-silica-content materials such as limestone and lime mortar. Because of the duration of the work tasks involving such materials for example, repointing a limestone building, it is often not possible to quantify RCS exposures using traditional sampling techniques with sample collectors operating between 1.7 and 2.2 l/min. As part of this study, an evaluation of high flow rate samplers (CIP10-R, GK2.69, and FSP10) for RCS exposure measurement at a restoration stonemasonry field site during work activities involving limestone and sandstone will be conducted as part of a larger study led by NIOSH (NIOSH, 2010).

2.5.2 Characterising RCS exposures of high risk occupational groups

Since RCS exposure is entirely avoidable; the prevention of such exposure through the reduction of RCS dust in the workplace is crucial. The characterisation of RCS exposures within an occupational group is imperative in order to design an effective approach to control such exposure. While occupational exposure to RCS is well documented in many occupational groups, to date, few (Seaton and Cherrie, 1998; HSE, 2009) studies have investigated occupational exposures to RCS amongst restoration stoneworkers and no studies have investigated suitable exposure controls amongst this occupational group. Restoration stone work can be distinguished from construction stone work by the use of tools and techniques specific to restoration work (English Heritage, 2012; Caroe, 2001). Restoration stone work regularly involves the application of fine decorative detail to stone, which often requires the worker to work in very close proximity to the exposure source. Restoration stoneworkers are also required to follow strict conservation guidelines and therefore, not permitted to substitute high silica content materials with low silica alternatives. This has far reaching implications as high silica containing materials such as sandstone have been used all over the world in the construction of buildings so, the workers responsible for the restoration of these buildings are at a high risk of being exposed to excessive levels of RCS. For this reason, it is important to collect information on high exposure tasks so that effective solutions can be implemented at site level to reduce worker exposure to RCS. In addition to this, there is limited research (Tjoe Nij *et al.*, 2003) on exposure controls such as shrouds for use with high silica content materials such as sandstone. It is essential to investigate exposure controls suitable for the high silica materials and tools used by restoration stoneworkers because of the high levels of RCS to which this group is potentially exposed and the different materials, tools and grinding wheels used means that exposure controls suitable for stone work tasks in other sectors may not be suitable for restoration stone work. The lack of RCS exposure data and suitable exposure controls for restoration stoneworkers are important research gaps and will be addressed as part of this research.

Health and Safety regulators such as the Irish Health and Safety Authority and the UK Health and Safety Executive have published guidance on RCS and controls to reduce exposure to RCS for the construction (HSA, 2010) and stonemasonry (HSE, 2006) sectors. These information sheets give little information on specific tasks associated with exposure to RCS outside of the construction sector (HSA, 2010) or for specific stoneworker groups (HSE, 2006). Stone work is very varied and includes many different groups, one of which is restoration stoneworkers. Restoration stone work is also different to construction work for the reasons already discussed. Developing guidance that refers to specific tasks and worker groups increases the chances that stoneworkers relate to guidance and use recommended exposure control measures. It is important to incorporate information on specific tasks and materials when developing guidance on likely exposure data for groups of workers and when drafting guidance on an occupational hazard. There is limited information available on workers personal exposure to RCS associated with specific stone restoration tasks and few studies have described suitable exposure controls. In order to provide realistic advice to the industry, the collection of data on specific tasks associated with high exposure to RCS is required.

Not only are stoneworkers potentially exposed to high levels of RCS dust amongst other hazards, stoneworkers are usually employed as freelance workers or in micro enterprises (< five employees) which could have implications for their health and safety whilst at work. In the UK, in 2005, 1200 stone masonry businesses were registered of which 65% employed less than four employees and 20% employed less than ten employees. Most of these were classified as micro businesses (< five employees). There was little evidence of consolidation or grouping in the industry. This has negative implications for the time, expertise and other resources available within the companies to be applied to health and safety issues and it also has adverse implications for the practicalities of communicating such information (HSE, 2009). Unlike large enterprises, freelance workers and micro enterprises do not have access to in-house health and safety officers or access to readily available health and safety information. There is a low priority given to health and safety in small businesses (HSE, 2007) and health and safety is not recognised as a key business objective (Vassie and Cox, 1998). Also, the down turn in the economy has greatly impacted the construction sector, and will have a knock on effect on workplace health and safety. In addition to this, they typically experience difficulty in identifying relevant regulations (Borley, 1997) and comprehending these regulations (Vassie *et al.*, 2000). The high proportion of fatalities and ill-health in the sectors that are made up solely of small or medium enterprises indicates that small or medium enterprises pose a high risk to the health and safety of workers employed in them. Self-employed workers and small enterprises have been identified as being hard to reach groups when implementing conventional health and safety initiatives (HSE, 2004). The implementation of health and safety in these workplaces pose unique challenges. In the HSA's Taking Care of Business Plan 2014-2016 and programme of work 2014 and 2013, they aim to increase the overall awareness of the small business sector of the benefits of good health and safety management and enable small businesses to efficiently manage safety and health. A better understanding of the health and safety culture within these enterprises could help the HSA develop strategies and guidance to improve health and safety practise in these workplaces which are often difficult to access. As part of this research, information will be collected from stone work enterprises in Ireland to collect data on health and safety practise and also to investigate the implication of this study for the wider stoneworker community in Ireland. It is envisioned that this information and the exposure data collected during the course of this research will help regulators develop guidance material and policy to address the gaps in guidance identified and help deliver key messages to the industry.

2.6 Objectives of research project

To address some of the research gaps discussed above, this project aims to characterise the RCS exposure of a group of restoration stoneworkers, identify the main determinants of exposure among this occupational group and develop and implement a workplace intervention to reduce worker exposure to RCS whilst carrying out high exposure tasks.

The specific objectives of this study are to:

- Characterise the respirable crystalline silica (RCS) exposure of a group of stoneworkers involved in the restoration of historical monuments in Ireland.
- To identify and investigate the contribution of determinants of respirable crystalline silica exposure amongst this occupational group and identify specific factors which influence variability in exposure levels within and between workers and depots.
- To design and execute a workplace intervention comprising of technical and worker elements to reduce worker exposure to RCS principally whilst carrying out the task of grinding sandstone within this occupational group.
- To investigate the implication of the exposure assessment and intervention part of this study for the wider stoneworker community in Ireland.
- To participate in an international field study led by the Health Effects Laboratory Division, Exposure Assessment Branch of NIOSH to investigate the performance of high flow rate samplers for the collection of low concentrations of RCS under restoration stone work field conditions.

3.0 Overview of chapter

The objective of this research was to a) characterise the respirable crystalline silica (RCS) exposure of restoration stoneworkers and identify and investigate determinants of RCS exposure b) design and execute a workplace intervention study focused on reducing RCS exposure in high exposure tasks c) investigate the implication of this study for the wider stoneworker community in Ireland and d) participate in an international field study to evaluate the performance of three high flow rate samplers fr the measurement of RCS during restoration stone work.

This chapter presents an overview of the project sampling strategy and the methodologies employed to meet the project objectives and are presented as follows: description of organisation and sites (Section 3.1); exposure assessment methodology (Section 3.2); data analysis (Section 3.3); workplace intervention (Section 3.4) and survey of Irish stoneworkers (Section 3.5).

3.1 Description of host organisation

The Commissioners of Public Works in Ireland (here and after referred to as the Office of Public Works (OPW)) is the Irish state agency responsible for the management of state property in Ireland. It employs approximately 2,000 employees in more than 100 locations around Ireland. The OPW's core services are property maintenance and management, architectural and engineering services, heritage services, project management and procurement services. This study was conducted in conjunction with the National Monuments and National Historic Properties units of Heritage Services. Heritage Services are responsible for managing, maintaining and preserving over 740 of Ireland's national monuments, including the Neolithic Newgrange, the early Christian Glendalough, Kilmainham Gaol and managing a range of historic properties which include over 20 houses, parks and gardens such as the Phoenix Park, the Blasket Centre in Co. Kerry and Altamont Gardens in Co. Laois.

This study was carried out over the period September 2009 - September 2013. Ethical approval for this study was obtained from the Research Ethics Committee of the National University of Ireland, Galway.

Staff were located in six centralised depots in Co. Galway, Co. Leitrim, Co. Cork, Co. Kilkenny, Co. Meath and Co. Kerry. Buildings Maintenance services are located in Co. Dublin.

A map showing the location of depots where sampling was carried out (Figure 3) and number of workers who participated in the study (Table 1) are as follows:

Figure 3: Locations of depots and field sites where sampling took place.

Table 1: Number of stone cutting workshops, stone cutters employed and stonemasons employed within each depot where sampling took place.

	Galway depot	Kilkenny depot	Kerry depot	Leitrim depot	Cork depot	Dublin depot
No. of stone cutting workshops	2	1	1	1	2	0
No. of stone cutters employed in depot	1	2	1	1	1	0
No. of stonemasons employed in depot	1	11	17	5	5	5

3.1.1 Study population

Participants were randomly recruited in coordination with the Health and Safety Unit and depot managers in the OPW. All participants in this study (*n*=35) were experienced stoneworkers employed as restoration stonemasons and stone cutters in OPW National Monument and Buildings Maintenance services. They worked at various field locations and workshops throughout Ireland. The stoneworkers were divided into two groups (stone cutters and stonemasons) based on their job title and job specifications and are detailed in Table 2.

Table 2: Description of job specifications of stoneworkers included in study

Job title	Job specification
Stone cutter	A stone cutter specialises in cutting stone. The majority of stone cutting is carried out in a workshop. In the workshop, this involves fabricating quarried stone to the rough size required for the finished piece, using a water cooled primary saw. If further significant cutting is required on site, a stone cutter uses a 5 inch, 9 inch or 12 inch angle grinder.
Stonemason	A stonemason performs several tasks including; the shaping of stone to the exact geometrical shape required for the finished piece, normally using a 5 inch angle grinder, addition of decorative detail to the finished pieces with hand and pneumatic chisels, arranging the resulting finished pieces in the monument and removing deteriorated mortar from a monument before repointing with new mortar. A stonemason carries out the majority of his work on site and rarely in the workshop.

3.1.2 Description of work tasks and materials used by the stoneworkers

Tasks evaluated

The restoration process commences in the workshop. Each workshop contains the following tools: a water cooled primary cutting saw and hand tools including disc polisher/cylinder polisher, 5 inch, 9 inch and 12 inch angle grinders, pneumatic chisel, hand chisel, brushing tools and hand punches. Depending on the level of restoration required an existing piece of stone from a monument is restored or it is re-made following the original design. In the workshop, all of the primary cutting and the majority of the shaping/grinding and decoration/scabbling/brushing of the stone takes place. The finished piece is then transported from the workshop and positioned in the monument. Some minor cutting and shaping of the stone may take place in the field but the majority of the work carried out in the field involves repointing. Traditional techniques are used to positioning a piece of stone in a monument and carrying out other restoration work such as repointing. Where restoration work is taking place on a monument over a long period of time, a temporary workshop may be set up in the field where cutting and shaping is performed.

Table 3 presents the tools and masonry accessories used by restoration stoneworkers when carrying out workshop and field based work tasks.

Work tasks evaluated, including workshop and field based work tasks

Workshop based work tasks

Primary cutting - Involves cutting a large quarried piece of stone to the rough size required for the finished piece using a water cooled primary cutting bridge saw with a 2 m blade. Water is applied to the blade via a recirculating tank at a rate of 100-120 l/min. This task is only carried out by a stone cutter. This task is usually carried out for 1- 5 hours per day.

Scabbling/brushing - involves applying a rough surface to the surface of a stone for example; to add a non-slip surface to a flagstone. This task is usually carried out by a stonemason for 40 mins - 2 hours per day.

Workshop based work tasks or work tasks occasionally carried out in the field

Cutting - Involves cutting stone to a smaller size with a 5 inch, 9 inch or 12 inch angle grinder. This task is usually carried out by the stone cutter and rarely by a stonemason. This task is usually performed for 30 - 40 minutes, 1- 4 times in a day.

Shaping/grinding - Involves shaping or grinding stone using one or all of the following tools - 5 inch angle grinder, pneumatic chisel, disc polisher and hand chisel. This task is usually performed by the stone cutter and rarely by a stonemason. This task is usually carried out for 30 – 40 minutes, 1- 4 times in a day.

Decoration - Involves finishing and applying decorative detail to stone using the following tools - pneumatic chisel, hand chisel, brushing tools and hand punches.

Field based work tasks

Repointing - is the process of renewing mortar joints. This involves the removal of old mortar by hand and replacing with new mortar of similar characteristics using a mason's trowel and hawk. This task is only carried out by a stonemason. This task is carried out by a stonemason for usually 3 - 5 hours per day.

Table 3: Tools and masonry accessories used by restoration stoneworkers when carrying out workshop and field based work tasks.

	
5 inch grinder and grinding wheels	 
9 and 12 inch grinder	 
Pneumatic chisel and chisel heads	 
Hand chisel	 
Trowel and hawk	 

Table 4: Materials used by the restoration stoneworkers during the study

Sandstone	
Limestone	
Granite	
Lime Mortar	

Materials used by the restoration stoneworkers during the study

In recent years, there has been a move to use traditional craft skills and traditional materials to repair, restore and conserve historic building fabrics (Bolton, 2006). As a monument is restored or repaired, the stone is sourced from the original quarry or alternatively, a quarry that can supply stone with similar properties to the original stone. A traditional lime mortar with similar components and properties to the original is used in the restoration process. The Irish building materials used by the restoration stoneworkers in this study were sandstone, limestone, granite and lime mortar and are described below.

Sandstone

Sandstone is a sedimentary rock consisting of sand or quartz grains cemented together (Table 4). Sandstones are classified based on their cementing material and range from very hard to soft sandstone, which is favoured for carvings. There are several varieties of sandstone in Ireland, including sandstone belonging to the Old Red Sandstone outcrop and Coal Measures geological formation, greywacke variety of sandstone, the flagstone of Co. Clare and Mountcharles sandstone. Examples of these different sandstones are evident in buildings and monuments around Ireland for example; Old Red Sandstone was used in the construction of Ardfert cathedral and Reginalds tower and Mountcharles sandstone was used in the building of the National Museum of Ireland in Dublin (Pavia and Bolton, 2000). Other examples of local types of sandstone used in Irish monuments include; Drumbane sandstone, Manorhamilton sandstone, Clara Hill sandstone and Killaloe sandstone which have a silica content ranging from 50% - 85% silica (Kissane and Pavia, 2008). By the end of the 17th century, quarrying had ceased in many Irish sandstone quarries and limestone became the building material of choice (Pavia and Bolton, 2000).

Limestone

Limestone is a sedimentary rock composed of the mineral calcite (Table 4). Limestone is the most abundant stone in Ireland and is currently quarried for cement production, lime and to supply aggregate and stone. In the past, local varieties of limestone were used as the primary building material in the construction of whole cities such as Galway and Drogheda. Historic buildings built from limestone include; Muckross abbey in Co. Kerry, Cork courthouse and Cong abbey in Co. Galway. A variety of

Dublin limestone known as Calp is present in Christchurch Cathedral and Collins Barracks to name a few buildings in the Dublin area (Pavia and Bolton, 2000). One of the most popular types of Irish limestone is Kilkenny or 'Irish Blue' limestone which consists of nearly 100% calcium carbonate and has a very low silica content (1 – 2%) (Pavia and Bolton, 2000; Chever, Pavia and Howard, 2010).

Granite

Granite is an igneous rock which forms from the slow crystallization of magma below the Earth's surface (Table 4). Typical granite is composed essentially of quartz and alkali feldspar, hornblende and mica. There are many varieties of Irish granite including; Leinster granite, Termon, Donegal, Carlow and Mourne granite. Leinster granite is the most popular granite used in Irish buildings and has a silica content of up to 30% (Pavia and Bolton, 2000). Carlow granite for example was used in the construction of Bagenalstown courthouse in Co. Carlow.

Lime mortar

Mortar is a composite material consisting of an aggregate and a binder, classified according to their binding agent (lime or cement) (Table 4). There are two types of masonry mortar: bedding and pointing. Similar to other materials, aggregate was traditionally sourced locally for example; beach sand, crushed sandstone, limestone and granite. Lime mortar consists of lime and an aggregate such as sand mixed with water and is one of the oldest known types of mortar in Ireland. The first use of lime mortar dates back to the construction of round towers and early Christian churches from the 5th to 12th century. The silica content of lime mortar depends on the silica content of the aggregate used but can make up a significant fraction of the aggregate in mortar (Pavia and Bolton, 2000). The composition of lime mortar used in St. Brendan's Cathedral in Co. Galway for example consisted of a lime putty binder with finely graded aggregate of calcareous composition (limestone sand) (Bolton, 2006).

3.2 Exposure Assessment of RCS in Restoration Stonework Methodology

3.2.1 Exposure assessment sampling strategy

The exposure assessment element of this study was carried out over the period November 2009 to July 2012. After implementation of a technical intervention at the OPW sites, post intervention samples were collected between January and March 2014. Prior to commencing the study, the researcher met with site managers and workers and presented an overview of the project objectives and proposed sampling protocols. Study participants were asked to complete a self-administered questionnaire, designed using information gathered during preliminary site visits and previous research in this area (Lumens *et al.*, 2001; HSE, 2009). The purpose of this questionnaire was to collect information on the tasks, specific tools, materials and clean-up methods frequently used by the worker in order to develop a contextual information protocol for field sampling. A convenience sampling approach was followed. Exposure measurements were carried out while workers performed tasks in workshops and on site. Detailed contextual information collected during the measurement period included: details about the task, tools, materials, exposure controls and respiratory protective equipment (RPE). This was collected on a contextual information sheet attached in Appendix B.

At the beginning of the study, a walk-through survey was carried out in each of the stone cutting workshops using a checklist to collect detailed information on exposure controls used. This checklist was developed with reference to similar studies (HSE, 2006; Renton *et al.*, 2010) and collected information on the following; design of local exhaust ventilation system (LEV), maintenance and effectiveness of the LEV including capture velocity, worker use of LEV and RPE, cleaning and housekeeping practices.

Before sampling commenced, the worker was asked to perform their work task as normal to ensure that the dust levels measured were representative of normal work activities. This included normal use of all tools, engineering controls and RPE. Task sampling was performed only and when sampling a work task, all preparatory work i.e. marking out of stone, moving of stone and clean-up activities after the task were monitored.

Sampling periods ranged from 30 – 375 minutes. Task-specific exposure data were expressed as 8hr TWA assuming that the RCS exposure for the remainder of the work shift was zero. It was assumed that the RCS exposure for the remainder of the work shift was zero for the following reasons; the worker was carrying out non stone work activities such as driving a forklift or transporting finished stone pieces to the monument and the worker being monitored was working away from the stone workshop or any colleagues carrying out stone work.

A combination of gravimetric sampling and direct reading techniques were used to quantify worker exposure to respirable dust and RCS and detail exposure patterns. The respirable dust content and the silica content of the dust was analysed following validated methods - HSE (2000) MDHS 14/3: General methods for sampling and gravimetric analysis of respirable and inhalable dust and HSE (2005) MDHS 101: Crystalline silica in respirable airborne dusts; direct on filter analyses by infrared spectroscopy and X-ray diffraction respectively. The equipment used and analysis carried out as part of the exposure assessment is detailed below.

3.2.2 Respirable dust and respirable crystalline silica measurement

Equipment used respirable dust measurement

- Higgins Dewell conductive plastic cyclone (Casella, Bedford, UK.)
- 5 µm pore size 25 mm pre-treated PVC filter
- Tygon tubing
- Air sampling pump (Sidekick pump; SKC Ltd, Dorset, UK.)
- Drycal primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA)
- Tweezers for handling filters
- Sartorius ME5-F Microbalance
- Sartorius static eliminator.

Preparation of equipment used for respirable dust measurement

- The cyclone samplers and Tygon tubing were cleaned before use. This involved the units being disassembled, the dissembled units and Tygon tubing being soaked in laboratory detergent solution, rinsed thoroughly with water and allowed to air dry thoroughly.
- PVC filters were conditioned for 24 hours in a humidity controlled balance room in the School of Physics, NUI Galway, before weighing to allow for all moisture in the filters to come into equilibrium with the balance room atmosphere.
- Each filter was passed under the Sartorius static eliminator before placing in cassette.
- The filters were placed in clean, dry 25 mm sampling cassettes using tweezers and wearing gloves.
- The weight of the filter and cassette was recorded, which was used to determine the respirable fraction of the dust. A Sartorius ME5-F Microbalance was used.
- Each sampler was labelled for identification and sealed with its protective cover to prevent contamination.
- Three blanks were weighed per ten samples.

Sampling train used for respirable dust measurement

- A Casella Higgins Dewell conductive plastic cyclone dust sampler was used to collect personal respirable dust samples.
- The sampling pump was calibrated with a ‘warm up’ cyclone and cassette which was not otherwise used using a Drycal calibrator and the flow rate was set at 2.2 l/min.
- A pre weighed filter and cassette was placed in the cyclone sampling head.
- Each sampling head was connected to a calibrated Sidekick sampling pump using Tygon tubing.
- Before sampling commenced, the worker was asked to perform their work task as normal to ensure that the dust levels measured were representative of normal work activities. This included normal use of all tools, engineering controls and RPE.

- The sampling head was fixed to the worker within 30 cm of his breathing zone ensuring the cyclone inlet was in a downward vertical position.
- The sampling pump was attached to the belt around the waist or harness. The pump was switched on and note was taken of the time at the start of the sampling period. The workers and the equipment were observed at least every 30 minutes throughout the sampling period. The sample identity and all relevant sampling data were recorded in the contextual information sheet.
- At the end of the sampling period the sampling pump was switched off and record was taken of the time.
- The sampler was disconnected from the sampling head.
- The filter cassette was covered with its protective cover to prevent contamination for transportation back to the lab.
- On return to a clean area the flow rate of the pump was measured with the 'warm up' cyclone and cassette with the Drycal flow meter.

Gravimetric analysis of respirable dust

- The samples and blanks were allowed to re-condition overnight in the balance room in School of Physics, NUIG, before re-weighing following the same protocol above.
- The cassettes and filters were weighed and the weights recorded.

Analytical analysis of respirable crystalline silica content of respirable dust

- After gravimetric analysis was carried out, the samples were labelled and shipped to a mineralogy laboratory at the Institute of Occupational Medicine Consulting Limited, Edinburgh, Scotland, UK.
- Personal respirable silica concentrations (crystalline silica and cristobalite) were quantified using X-Ray diffraction using a method based on MDHS 101 (HSE, 2005), in a mineralogy laboratory run by the Institute of Occupational Medicine Consulting Limited, Edinburgh, Scotland, UK. The detection limit for quartz and cristobalite on filters by XRD was 20 µg.

3.2.3 Photometric measurement of respirable dust

Equipment used for photometric measurement of respirable dust

- Sidepak AM510 personal aerosol monitor (TSI Incorporated, Shoreview, MN, USA)
- A non-size selective impactor (TSI standard inlet with no impactor insert installed)
- Dorr-Oliver cyclone attachment
- Tygon tubing
- Primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA)

Preparation of equipment used for photometric measurement of respirable dust

- The impactor was cleaned before each use to remove accumulated particles. This involved removing the impactor from the instrument and removing the particles.
- The Dorr Oliver cyclone was cleaned before each use. This involved the unit being disassembled, soaked in laboratory detergent solution, rinsed thoroughly with water and allowed to air dry thoroughly before reassembly.
- The log interval was set to 1 minute and the calibration factor was set to factory calibration factor of 1.
- The monitor was calibrated using a Drycal flow meter and the flow rate was set at 1.7 l/min.
- The monitor was 'zeroed' using a zero filter.
- The Dorr Oliver cyclone was attached to the Sidepak via Tygon tubing.

Sampling train used for photometric measurement of respirable dust

- The Sidepak AM510 personal aerosol monitor was used to quantify worker exposure patterns. A Dorr-Oliver cyclone attachment was connected to a calibrated Sidepak monitor Tygon tubing. The flow rate was set at 1.7 l/min.
- The cyclone was fixed to the worker within 30 cm of his breathing zone. The sampling pump was attached to the belt around the waist or to a

harness. The pump was switched on and note was taken of the time at the start of the sampling period.

- The workers and the equipment were observed at least every 30 minutes throughout the sampling period. The sample identity and all relevant sampling data were recorded in the contextual information sheet.
- At the end of the sampling period the sampling pump was switched off and record was taken of the time. On return to a clean area the flow rate of the pump was measured with the Drycal flow meter.
- Recorded data was downloaded using TrackPro software.

3.2.4 Survey of Irish stoneworkers

The objective of this questionnaire was to examine different areas of health and safety practice amongst Irish stoneworkers and to investigate the implication of the findings amongst restoration stoneworkers for the wider stoneworker community in Ireland.
A self-administered quantitative questionnaire (Appendix C) was employed in this study and was designed using previous studies in the area (HSE, 2009) in addition to information gathered during site visits. The questionnaire consisted of 5 sections including 49 closed questions, 11 open ended questions and 4 likert scale questions designed to acquire information on (a) worker demographics; (b) work and work history (tools, materials, exposure controls used); (c) knowledge of health and safety (safety training and documentation); (d) workplace hazard identification and (e) health (smoking habit, self and doctor diagnosed respiratory illnesses). A pilot of the questionnaire was conducted with four stoneworkers from the sculptor, monumental and stone restoration trades. Amendments were made based on the results of the pilot study. A convenience sampling approach was followed. The questionnaire was posted to a sample of 130 stone workers from a population of 423 from various occupations throughout the Republic of Ireland. Stone workers contact details were identified, using national and on line directories associated with sculptors, monumental stonemasons trades excluding construction workers. These directories included ones taken from the Crafts Council of Ireland and www.build.ie. The questionnaire was posted with an explanatory cover letter to all identified stoneworkers and reminder phone calls were used to follow up with all non-responders.

Analysis questionnaire survey of Irish stoneworkers

All statistical analyses were performed using GenStat software (14^{th} Edition) (VSN International ltd). Questionnaire survey data was analysed in GenStat. Responses were divided into two datasets based on materials worked on using two categories of materials - sandstone and other materials. Descriptive statistics were used to characterise the demographics, materials and tools used, health and exposure control usage among the participants.

3.2.5 Inter-comparison of high flow samplers for respirable crystalline silica measurement

Over the course of the study, the researcher was invited to participate in an international field study led by the Health Effects Laboratory Division, Exposure Assessment Branch of the National Institute for Occupational Safety and Health (NIOSH). The objective of this study was to evaluate the performance of high flow rate samplers for RCS exposure measurement under the restoration stone work field conditions described in section 3.1. This was achieved by carrying out a field trial to measure respirable dust and RCS using three high flow rate samplers (CIP10-R, GK2.69 cyclone and FSP10 cyclone) and two reference low flow rate samplers (10-mm nylon and Higgins-Dewell (HD) cyclones) under typical restoration stone work field conditions.

Sampling strategy intercomparison of high flow samplers for respirable crystalline silica measurement.

This element of the study was carried out over a 10 month period between November 2011 and August 2012. A convenience sampling approach was followed. Intercomparisons of high flow sampler measurements were carried out in four OPW depots, one OPW field site and on one freelance stoneworker in Co. Sligo. Workers carried out the tasks of cutting and grinding sandstone and limestone. Prior to commencing these measurements, the researcher met with site managers and workers in each of the participating sites and presented an overview of the project objectives and proposed sampling protocols. 19 trials were carried out with the three high flow samplers using a Higgins Dewell cyclone as the reference sampler and 19 using a 10-mm nylon cyclone as the reference sampler. Sampling times ranged from 10 to 60 minutes, depending on the silica content of the material being worked. Detailed contextual information collected during the measurement period included: details about the task, tools, materials, exposure controls and RPE. This was collected on a contextual information sheet attached in Appendix B.

Equipment used for respirable dust measurement with high flow samplers

- Drycal primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA)
- Filter holders (SKC Inc.)
- Tachometer
- Tweezers for handling filters
- Tripod designed to hold a number of sampling heads at once.
- Sartorius ME5-F microbalance
- Mettler AE240 analytical balance
- Sartorius static eliminator.

Table 5: High and low flow samplers used in intercomparison study

Samplers		Flow rate (l/min)	Sampling media	Pump
10-mm nylon cyclone (Sensidyne, USA)		1.7	PVC filter (37 mm, 5µm pore size)	Sidekick
Higgins Dewell cyclone (Casella, Bedford, UK)		2.2	PVC filter (25 mm, 5µm pore size)	Sidekick
CIP10-R (Arelco ARC, France)		10	Polyurethane foam	-
GK2.69 (BGI Inc.,USA)		4.4	PVC filter (37 mm, 5µm pore size)	SKC Legacy
FSP10 (BIA, Germany)		11.2	PVC filter (37 mm, 5µm pore size)	SG10-2

Preparation of all sampling equipment used for respirable dust measurement with high flow samplers

- The cyclone samplers and cassettes were cleaned before use. This involved the units being disassembled, soaked in laboratory detergent solution, rinsed thoroughly with water and allowed to air dry thoroughly before reassembly. The CIP10-R sampler was cleaned using compressed air.
- PVC filters and polyurethane foams were conditioned for 24 hours in a humidity controlled balance room before weighing to allow for all moisture in the filters to come into equilibrium with the balance room atmosphere.
- Each filter was passed under the Sartorius static eliminator before placing in a cassette or rotating cup depending on the sampler.
- Pre-weighing was performed with a micro analytical balance (Sartorius ME5-F Microbalance) for PVC filters and an analytical balance (Mettler AE240) for rotating cups with polyurethane foam.
- Each cassette or foam was labelled for identification and sealed to prevent contamination. Extra filters were transferred on site in labelled filter holders.
- Where sample media was transferred to a cassette on site, compressed air was used to clean cyclones in between samples and a Sartorius static eliminator was used to eliminate static from the sample media.
- The Higgins Dewell cyclone and 10-mm nylon cyclone with filter was connected to the Sidekick sampling pump via Tygon tubing and calibrated using a Drycal calibrator and the flow rate was set at 2.2 l/min.
- The GK2.69 cyclone was connected to the Legacy pump via Tygon tubing and calibrated using a Drycal calibrator and the flow rate was set at 4.4 l/min.
- The FSP10 cyclone was connected to the SG 10-2 pump via Tygon tubing and calibrated using a Drycal calibrator and the flow rate was set at 11.2 l/min.
- The flow rate of the CIP10-R was initially set using a calibration table in a NIOSH lab and was checked on site using a tachometer to measure the rotational speed (RPM) of the cup. The flow was set at 10 l/min

Sampling train for respirable dust measurement with high flow samplers

- Before sampling commenced, the worker was asked to perform their work task as normal to ensure that the dust levels measured were representative of normal work activities. This included normal use of all tools, engineering controls and RPE.
- The GK2.69 cyclone and CIP10-R sampling trains with corresponding Higgins Dewell cyclone or 10-mm nylon cyclone sampling trains were placed on a tripod approximately within 1.5 m from the work process or worker.
- The cyclones were attached to a length of ply wood attached to the tripod and were positioned ensuring the cyclone inlet was in a downward vertical position.
- The FSP10 cyclone sampling train with corresponding Higgins Dewell cyclone or 10-mm nylon cyclone sampling train was mounted on the worker.
- The sampling head was fixed to the worker within 30 cm of his breathing zone ensuring the cyclone inlet was in a downward vertical position
- The sampling pump was attached to the belt around the waist or harness.
- All pumps were switched on and a note of the time was taken at the start of the sampling period. The workers and the equipment were observed at least every 30 minutes throughout the sampling period. The sample identity and all relevant sampling data were recorded in the contextual information sheet.
- At the end of the sampling period the sampling pumps were switched off and a record was taken of the time.
- The samplers were disconnected from their corresponding sampling heads.
- The filter cassettes, filter holders and polyurethane foams were covered to prevent contamination and transported back to the lab.
- On return to a clean area, the flow rates of the pumps were measured with the Drycal flow meter.

Gravimetric analysis of respirable dust

- The samples were allowed to re-condition for 24 hours in the balance room before re-weighing.
- The cassettes with filters, filters and polyurethane foams were weighed and results recorded.
- All methods in line with HSE (2000) MDHS 14/3 General methods for sampling and gravimetric analysis of respirable and inhalable dust.
- Dusts from the CIP10-R polyurethane foams were extracted by adding isopropyl alcohol to the foam in its rotating cup. These were placed in an ultrasonic bath for 5 minutes. The alcohol was then squeezed from the foam onto a 37 mm PVC filter through a funnel with a vacuum applied. The cup and foam were rinsed twice more with isopropyl alcohol to remove all dust. The filters when dry, were placed in labelled filter holders.

Analytical analysis of respirable crystalline silica content of respirable dust

- The cassettes, filters and polyurethane foams were labelled and shipped to the Exposure Assessment Branch, Health Effects Laboratory Division (HELD), National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC), Morgantown, West Virginia, USA.
- Personal respirable silica concentrations were quantified following method NIOSH Method 7500, Silica, Crystalline by XRD. NIOSH Manual of Analytical Methods (NMAM), Fourth Edition at Bureau Veritas laboratory in Atlanta, GA, USA.

3.3 Data analysis

3.3.1 Analysis of respirable crystalline silica (RCS) exposure data

The airborne concentration of RCS (mg/m^3) was calculated as the mass on the filter (mg) divided by the air volume (m^3). The volume of air sampled was calculated by multiplying the average measured sampling flow rate (litre/minute) by the sampling time (minutes). Task-specific exposure data were expressed as 8-hr TWA.

Equation 1: 8-hr TWA exposure concentration calculation

$$\text{Concentration } (mg/m^3) = \frac{\text{Mass collected (mg)}}{\text{Flow rate (l/min)}/1000 \times \text{sampling time (mins)}}$$

$$\text{8-hr TWA exposure concentration} = \frac{\text{Concentration } (mg/m^3) \times \text{sampling time (mins)}}{480 \text{ (mins)}}$$

It was assumed that the RCS exposure for the remainder of the work shift was zero for the following reasons; the worker was carrying out non stone work activities such as driving a forklift or transporting finished stone pieces to the monument and the worker being monitored was working away from the stone workshop or any colleagues carrying out stone work. The normality of the 8-hr TWA exposure data was examined initially using box plots. The exposure data was found to be approximately log normally distributed and was natural log transformed. Worker 8-hr TWA exposure data was categorised into similar exposure groups based on the material with which they were working. Each material group was categorised further by task performed. The geometric mean (GM) and geometric standard deviation (GSD) of the 8-hr TWA average exposure data for each material and task group were calculated. This was done by taking the mean and standard deviation of the logged data and then taking the exponential of these.

For testing compliance with the Occupational Exposure limit value (OELV) the procedure described in the joint document by the British and Dutch occupational hygiene societies (BOHS and NVvA) on ‘Testing Compliance with Occupational Exposure Limits (OELs) for Airborne Substances’ (BOHS, 2011) was followed. Exposure data were categorised into similar exposure groups based on material and task and compliance was estimated by comparing the 95th percentile of the exposure distribution with the OELV. Also, a group compliance test (with the OELV) was carried out by calculating the parameter U which was then compared with the limiting values of U given in France (2009). The parameter U = [log (OEL) – log GM] / log GSD (BOHS, 2011).

Statistical analyses of RCS worker exposure data

All statistical analyses were performed using GenStat software (14th Edition) (VSN International Ltd). Due to the large number of measurements below the analytical limit of detection (LOD) (0.02 mg/m^3) for measurements involving limestone (n=22) and lime mortar (n=13), statistical analysis was carried with exposure data for sandstone and granite only (n=65) as the dependant variable. The log transformed RCS 8-hr TWA data was summarised by each fixed variable (material worked on, worker task, respiratory protective equipment (RPE), local exhaust ventilation (LEV), job title, weather and level of enclosure) in order to investigate the distribution of data within each group. RPE and LEV each had two levels depending on whether they were present or not. Enclosure had three possible levels (indoors, outdoors and partial enclosure) while weather was grouped into six levels (wet and windy, dry and windy, wet and still, dry and still, showers and damp and sunny).

A generalised linear model with one variable was carried out to examine the relationship between each fixed variable and the log transformed RCS concentration (8-hr TWA). This was used to identify potential independent variables that would be considered for the multiple regression model. In order to investigate if combinations of variables were significant and to investigate their contribution to the individual's mean exposure, a multiple linear regression model was applied to evaluate the relationship between the fixed variables and the log transformed RCS 8-hr TWA concentrations. This was carried out by forward stepwise regression where variables significant at the $P \leq 0.001$ level were added one at a time and the least significant variables dropped until no improvement to the model was made. The results of the regression modelling were reported as β, SE and Exp (β). β is the coefficient of the fitted line from the regression modelling and SE is the standard error of the estimated β. As the regression modelling was carried out with data on the log-scale, the back-transformation of the β (Exp(β)) was also determined. In this context, the Exp(β) could be described as the ratio of the GMs and can be interpreted as the percentage increase (or decrease) in exposure associated with the factor (as compared to the baseline factor level).

In order to examine if significant variables from the regression model were still significant when random variance was included in the model and to investigate the extent of reduction in the between-depot, between-worker (within-depot) and within-worker variance components, generalised linear mixed model analysis was carried out. Forward inclusion of the significant variables from the regression model was carried out using the log transformed RCS 8-hr TWA data as the dependant variable. Three sources of random variance were investigated:

- Between-workers variation – This variation is the difference in factors that define the work conditions of different workers. These factors are mostly spatially related (e.g. LEV), varying among workers but constant in time for each worker. Sometimes these factors are both spatial and temporal. This variation can also be differences among workers beyond what can be explained by specific factors e.g.: lack of awareness (Peretz *et al*, 2002). Due to the natural nesting of workers in depots in this study, between worker within depot variability was investigated.
- Within-worker variability - This variation is the differences in factors that define the work conditions of the same worker over time. These factors are temporal and may be common to all workers in a similar exposure group. This variation can also be differences among workers beyond what can be explained by specific factors e.g. lack of awareness or measurements taken by different hygienists (Peretz *et al*, 2002).
- Between-depot variability - This variation is the difference in factors that define the work conditions at different depots.

The normality of the data was examined post modelling by checking the normality of the residuals from the final model output. This was carried out to check that the assumption of normality made was plausible after taking into account any factors that had been fitted in the model.

Exposure measurement less than the limit of detection (LOD) of the analytical method for RCS were substituted using methods described by Hornung and Reed 1990 and

Luben *et al*, 2004. The first method involved substituting values less than the LOD with a constant value of half the LOD (0.01 mg/m^3). As this can produce questionable descriptive statistics depending upon the percentage of values below the LOD, a second method was also employed. The second method involved the substitution of the below LOD values with randomly imputed values between zero and the LOD (0.02 mg/m^3) which resulted in a set of values ranging from 0.000028 to 0.017 mg/m^3. A single imputation was carried out. This was carried out using SAS Statistical Software (SAS Institute, Cary, NC, USA)

3.3.2 Analysis of photometric data

Photometric data was downloaded from the SidePak using TSI Trackpro software. This data was used to quantify worker exposure patterns whilst different tasks were carried out. The SidePak was pre-calibrated by the manufacturer with Arizona road dust (ISO 12103, Al ultrafine test dust) which is the factory default calibration factor of 1. A series of custom calibration factors were determined to investigate differences between the Arizona road dust and the dusts being measured during the study. These custom calibration factors were determined by running the SidePak monitor and gravimetric respirable dust sampler side by side during exposure measurements (*n*=66) in accordance with the manufacturer's application note (ITI-099). This data was used to calculate approximate correction factors for four different dust types (limestone, lime mortar, hydraulic lime and sandstone) using equation 2.

Equation 2: Custom calibration factor

$$\text{Custom calibration factor} = \frac{\text{Reference concentration}}{\text{Data log concentration}} \times \text{ECF}$$

Reference Concentration = Gravimetric Concentration

Data Log Concentration = Photometric Concentration

ECF = Existing Calibration Factor

3.3.3 Analysis of high flow sampler data

Both the mass concentration ratio and net mass ratio were calculated in order to compare the net and mass concentrations determined by the high flow rate samplers with those determined by the low flow rate cyclones. The mass concentration ratio was defined as the mass concentration from each high flow rate sampler divided by the mass concentration measured with either the 10-mm nylon cyclone or the Higgins Dewell cyclone. The net mass ratio was defined as mass collected by each high flow rate sampler divided by the mass collected by the nylon cyclone or Higgins Dewell cyclone.

3.4 Workplace intervention study

3.4.1 Study design

The second element of this work involved the design and execution of a workplace intervention study which focused on reducing RCS exposures when grinding sandstone with a 5 inch angle grinder. The intervention focused on the work task of grinding sandstone with a 5 inch angle grinder because highest RCS exposures were recorded for this task during the exposure assessment element of the study.

It was decided that a workplace intervention, incorporating both technical and worker elements would be implemented amongst the restoration stoneworkers. The technical element of the study involved evaluating the effectiveness of four commercially available shrouds at reducing respirable dust and RCS exposures for the task of grinding sandstone with a 5 inch grinder. The worker element involved collecting information, using a self-administered questionnaire survey on worker use of exposure controls and examining individual and organisational factors which influence worker use of exposure controls. The findings from this questionnaire were used to develop a training programme for workers and compile recommendations for the host organisation, the OPW, concerning organisational changes to improve worker use of exposure controls.

3.4.2 Technical intervention selection of exposure controls

The hierarchy of exposure controls (Schedule 3 of the Safety, Health and Welfare at Work Act, 2005) was followed in order to source an appropriate control to reduce exposure to RCS during the task of grinding sandstone. In the case of the restoration of historic monuments in the OPW, the elimination or substitution of sandstone is not feasible as conservation guidelines require the use of traditional materials (Irish National Monuments Acts, 1930 to 2004). For this reason, the implementation of an engineering control to reduce exposure was deemed to be the best option.

Engineering controls investigated

The following engineering controls were investigated; an exhaust ventilation booth, flexible isolator, mechanical room ventilation, modification of existing capture arms, water suppression and shrouds.

a) Exhaust ventilation booth

Following guidance published by the UK Health and Safety Executive (HSE) on recommended engineering controls for grinding stone, an exhaust ventilation booth (cross-draught booth) was investigated as the most suitable engineering control for the task of grinding sandstone (HSE, 2001; HSE, 2006). Meetings were held with various containment engineers including; Containment Service Providers, UNIFLO and Crossflow and with four stoneworkers from one of the OPW depots to discuss their work needs. Options regarding an exhaust ventilation booth, flexible isolator, mechanical room ventilation and modification of existing capture arms were discussed with the containment engineers and are detailed below.

- Many of the ventilation booths commercially available and reviewed were specific to the pharmaceutical and chemical industry and would not be suitable for a stone workshop. This option was not investigated further due to lack of space in the workshops and the cost of these units was prohibitive.
- A flexible isolator with an airflow system similar to a fume hood made from heavy duty plastic was also reviewed. This isolator included a removable front flap with arm holes that the operator could lift up depending on the task. This option was not investigated further for the following reasons; the impracticability of a flexible unit in a stone workshop, the potential for abrasive dust to damage the flexible material and potential issues placing larger pieces of stone into the isolator.
- Two final exposure control options were investigated; mechanical room ventilation and modifying existing capture arms used in conjunction with RPE. Mechanical room ventilation was not investigated further due to the potential for it to spread dust around the workshop and pull the dust past the worker's breathing zone rather than capturing it at source. Reliance on RPE was not deemed a suitable exposure control approach.

b) Water suppression

Water suppression is also recommended as an engineering control by the HSE for work with rotary tools (HSE, 2001; 2006) such as 5 inch grinders with stone. This was not selected as a suitable engineering control for the following reasons;

- In the workshops, drainage systems would have to be installed to deal with the water/slurry from the tool with the water suppression.
- The water could itself provide a new hazard by making the floor slippery
- The majority of the workers that were consulted regarding the introduction of water suppression were opposed to the idea because of the cold conditions in which they work on site and the fact that they would have to wear waterproof overalls.

c) Shrouds

The exposure controls discussed above were not deemed acceptable for the task of grinding within this occupational group. It was concluded that a shroud was the most feasible option for controlling dust from grinding for the following reasons; numerous studies had demonstrated that the use of a shroud can substantially reduce respirable dust and RCS exposure concentrations whilst grinding in the construction sector (Echt and Sieber, 2002; Akbar-Khanzadeh and Brillhart, 2002; Croteau *et al.,* 2004; Akbar-Khanzadeh *et al.,* 2007; 2010), they were suitable for both work shop and mobile field based tasks, they captured dust at source, they could be retrofitted onto existing grinders and were relatively inexpensive. A shroud is a cover which fits onto the bearing housing of an angle grinder and results in the grinding wheel being enclosed or partially enclosed by the shroud. A vacuum source is attached to the shroud and removes dust generated by the grinder at source. The dust is then captured in the filter of the vacuum unit and clean air exhausted to the external environment.

A technical intervention study was designed to evaluate a range of commercially available shrouds for reducing RCS exposures when grinding sandstone with a 5 inch angle grinder. The design and execution of the technical intervention study is described below:

3.4.3 Technical intervention evaluation of shrouds

Site location and description

This study was repeated on three occasions at an OPW stone workshop. The site had access to sufficient quantities of sandstone, stationary and mobile vacuum units, 5 inch grinders and grinding wheels needed in order to carry out the trial. The measurements were conducted in the semi enclosed workspace adjacent to the stone workshop. The workspace had a corrugated metal roof and was enclosed on three sides by a plastic mesh and was open to the front. The workspace comprised of a bench and a rotating banker which is a type of stonemasonry bench and had facility for on-tool LEV systems connected to a Nederman (Helsingborg, Sweden) L-PAK 250 compact stationary high vacuum unit in the workshop. Two experienced restoration stoneworkers were recruited for the evaluation of all exposure controls in this study. One stoneworker participated in trials one and two and the second stoneworker participated in trial three. During this study, workers wore a powered air purifying respirator (PAPR) or an FFP3 dust mask both with an assigned protection factor of 20.

Selection and description of workers

Two experienced restoration stoneworkers located in the Co. Kerry depot were employed for the evaluation of all exposure controls in this study. Worker participation in this study was voluntary. During this study, workers wore a powered air purifying respirator (PAPR) or an FFP3 dust mask.

Selection of tasks for evaluation

During the first trial, sandstone was shaped to fabricate and assemble a sandstone fireplace for a castle, while during the second and third trial a sandstone window jamb, the main vertical parts forming the sides of a window frame, for a castle was constructed. These tasks required the worker to use various abrasive grinding wheels, reflecting typical work and exposure patterns within this occupational group. All work was performed on a rotating banker. The fireplace comprised of one 91 cm x 20 cm x 23 cm lintel the opening of which was formed by a 55 cm, 45° chamfered arch. The chamfered width was 5.5 cm which was formed on site with a grinding tool. The rest of the fireplace was made up of 4 upright 33 cm x 20 cm x 22 cm blocks that were also chamfered. The chamfer on these blocks was 1.5 cm. The window jambs were created from a 28 cm x 26.5 cm x 28 cm block of sandstone. The window jamb was formed on site to give a final piece with a bottom width of 26.5 cm, a top width of 12.5 cm and sides measuring 19.5 cm, tapered to 8.5 cm at the top and 19.5 cm, tapered to 4 cm at either end. All work was performed on a rotating banker.

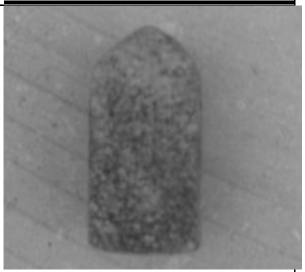
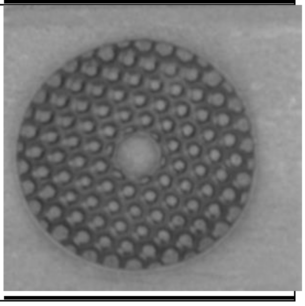
Selection of tools and accessories for evaluation

Two hand held electric powered grinders were used in this study; a FLEX (Steinheim, Germany) grinder and a Hilti (Schaan, Liechtenstein) grinder (Table 7). Over the course of the trials, the FLEX grinder was equipped with five different grinding wheels commonly used in restoration stone work. These grinding wheels and their specified rpm are detailed below;

- Diamand Teck (Rathcoole, Dublin, Ireland) Diamond turbo cup grinder, 10 cm operating at 4000 rpm
- Diamand Teck 12.2 cm Multi cutter diamond cup wheel operating at 4500 rpm
- FLEX (Steinheim, Germany) 10 cm Velcro diamond disc grade 50 (coarse) operating at 2000 rpm
- Bavaria (Landsberg am Lech, Germany) 10cm Corundum grinding ring grit 30 with adapter plate operating at 4000 rpm
- Bavaria (Landsberg am Lech, Germany) Corundum grinding point operating at 3000 rpm

Certain grindings wheels (Diamond turbo cup grinder, Multi cutter diamond cup wheel) were used to remove excess stone from a sawn block of stone and other grinding wheels (Corundum grinding point, Velcro diamond disc grade 50) were used to create a smooth finish on the flat, in corners and around decorative details (Table 6).

Table 6: Grinding wheels evaluated with FLEX grinder

Diamand Teck diamond turbo cup	
Diamand Teck 12.2 cm multi cutter diamond cup wheel	
Bavaria 10 cm corundum grinding ring grit 30	
Bavaria corundum grinding point	
FLEX 10 cm Velcro diamond disc grade 50 (coarse)	

Selection of shrouds for study

Eight commercially available shrouds were sourced via consultation with vendors such as Hilti Ireland, PWM distribution and Dustless Technologies (Table 7).

Configuration 1. FLEX grinder equipped with a shroud manufactured by FLEX (Steinheim, Germany). This shroud was made of steel and had a diameter of 13.5 cm. The exhaust port was 2.7 cm in diameter and was positioned on the right side of the grinder.

Configuration 2. FLEX grinder (Steinheim, Germany) with Dust Muzzle shroud (East Yorkshire, UK). This shroud was made of polypropylene and had a diameter of 15 cm. Air entered the shroud through seven vacuum relief holes (diameter 9 mm) positioned on the front exterior. The side exhaust port was positioned on the right side of the grinder and had a diameter of 3 cm. The shroud had an adjustable collar and attached to the bearing housing of the grinder using an adjustable collar ring. The combination of the adjustable collar and collar ring was designed to accommodate different bearing housing diameters. In order for this shroud to be fitted onto the FLEX grinder, 1.8 cm had to be trimmed off the collar by the worker to adjust the height. Also, an 8 cm x 2.5 cm section was cut from the skirt of the shroud using a saw in order to expose the leading edge of the blade. This modification was carried out by the worker and was essential in order for the worker to cut into corners on the stone.

Configuration 3. FLEX grinder equipped with a Dustie® (Dustless Technologies, Utah, USA) shroud which was made from flexible lightweight plastic. This combination was used with the Nederman L-PAK 250 compact stationary high vacuum unit. The diameter of this shroud was 14.5 cm and similar to the Dust Muzzle, had ten rectangular 0.8 cm x 0.1 cm vacuum relief holes positioned on the front exterior. The attachment collar of this shroud was a FLEX-Flange™ which allowed it to fit to various bearing housings and was fitted to the grinder using an adjustable collar ring. 0.7 mm was trimmed off the flange by the worker to fit it on the bearing housing. The section that was cut from the front was 7.5 cm x 2.5 cm along the 'TP' line. Two cut lines were moulded into the shroud in order to aid the cutting of it to expose the tip of the grinding wheel. The cut line selected depended on the worker's directional preference when cutting. The side exhaust port was located on the right hand side and had a 2.9 cm diameter.

Configuration 4. Hilti grinder with diamond grinding cup equipped with a shroud system manufactured by Hilti (DG-EX 125 dust extraction hood). This combination was used with the Hilti VC20-U portable jobsite vacuum. This shroud was constructed of high density plastic and had a diameter of 15.5 cm with a 3.3 cm diameter take-off located to the right. The shroud had nine 0.4 cm vacuum relief holes positioned on the bottom of the exterior. The shroud had a design feature, which enabled the worker to slide the front rim of the shroud to the left in order to cut into corners. This grinder operated at 11,000 rpm, in trial one it was concluded that this was too high a rpm for this type of stone work and for this reason, this on- shroud was not tested in trials 2 and 3.

Table 7: Grinders and shrouds evaluated in study

FLEX grinder equipped with shroud manufactured by FLEX	
FLEX grinder equipped with Dustie® shroud	
FLEX grinder equipped with Dust Muzzle shroud	
Hilti grinder equipped with DG-EX 125 shroud	

Vacuum sources used in the study

A Nederman (Helsingborg, Sweden) L-PAK 250 compact stationary high vacuum unit with a HEPA filter was used to provide vacuum for three (FLEX, Dustie®, Dust Muzzle) of the shrouds tested. The unit (dimensions 1.3 m x 1.1 m) was located in the workshop and was connected to an exterior wall via a length of corrugated hose. This extended down the exterior wall via a 50 mm diameter metal hose with a valve on the end. This valve had a micro switch which opened automatically when a connected tool was powered on. The tool was connected to the exterior hose via a flexible 5 m long, 3.5 cm diameter corrugated hose. The unit had a two stage filter followed by a HEPA filter (99.997 % efficiency). This vacuum unit automatically cleaned its filter by blasting reversed atmospheric air through its surface treated polypropylene filter socks every 60 seconds, dislodging any dust that may have accumulated into a container located below the unit. For the harmonised Hilti set up – the vacuum used was Hilti's VC20-U portable jobsite vacuum (Schaan, Liechtenstein). This vacuum was a dry/wet vacuum cleaner and is marketed for 'removing dust from drilling, slitting, grinding, cutting and dry coring'. The portable vacuum had the dimensions 0.5 x 0.38 x 0.5 m and a weight of 13.5 kg. The vacuum was equipped with a standard disposable filter. The vacuum was conveyed to the tool via a flexible 5 m long 3.6 cm diameter corrugated hose. This vacuum was equipped with an automatic filter cleaning system, which cleaned the filter every 15 seconds to provide consistently high suction performance (Table 8)

Table 8: Vacuum sources utilised in study

Hilti VC20-U mobile jobsite vacuum (Schaan, Liechtenstein)	
Nederman (Helsingborg, Sweden) L-PAK 250 compact stationary high vacuum unit with a HEPA filter	

Experimental design

Evaluation of the effectiveness of the shrouds at reducing airborne respirable dust and RCS concentrations was assessed by collecting photometric (n = 112) and RCS (n = 56) data. There were three trials and measurements were repeated eight times within a trial. Each trial lasted one day. For the FLEX grinding tool, one trial resulted in eight photometric and four RCS measurements using the FLEX grinding tool with no shroud and eight photometric and four RCS measurements for each of the three shrouds tested, with a total of 32 photometric and 16 RCS measurements for each trial. The Hilti shroud was evaluated in the first trial only where eight photometric and four RCS measurements were taken using the Hilti tool with no shroud and eight photometric and four RCS measurements for the Hilti shroud. The measurement duration was 15 min with and 10 min without a shroud. These sampling durations were selected based on anticipated levels of exposure concentrations during the task evaluated. The measurement duration without a shroud was reduced in order to avoid exposing the worker to high levels of RCS when grinding sandstone. Measurements without a shroud were collected at the end of each trial to reduce background contamination during the shroud measurements. In all three trials, the measurements with and without a shroud were collected in direct succession to maintain consistent parameters such as weather conditions. The order in which the shrouds were evaluated varied randomly, ensuring that differences in technique used at the beginning and end of the process would not affect the evaluation of the shrouds.

This methodology was developed following previous similar studies detailed in Table 9.

Table 9: Summary of studies investigating the effectiveness of exposure controls at reducing exposure to respirable dust and RCS.

Author (s)	Tasks & exposure controls investigated	Materials used (% silica content)		Sampling time (mins)	% respirable dust reduction	% RCS reduction
Shepherd and Woskie, 2013	Cutting 14 inch con saw, water suppression	Concrete*	178	3 – 9 mins	85%	Not reported
Middaugh *et al.*, 2012	Cutting 14 inch con saw, shroud, water suppression	Concrete (5.8 - 7.5%)	43	4 – 16 mins	73 – 78%	66% (estimated value)
Meeker *et al.*, 2009	Abrasive cutter, stationary saw, tuckpointer, shroud, water suppression	Concrete, brick, mortar*	50	5 – 25 mins	> 90%	91 – 96 %
Shepherd *et al.*,2009	Hammer drill, shroud	Concrete*	18	15 - 60 mins	> 90%	93 – 98%
Echt et al., 2007	Abrasive cutter, stationary saw, tuckpointer, shroud, water suppression	Concrete block (24 - 54%)	33	5 - 10 mins	95-99%	95%
Croteau *et al.*, 2004	Grinding 5 inch grinder, shroud	Concrete (3-10%)	56	32 – 47 mins	92%	80 – 92% (GM RCS)
Tjoe Nij *et al*, 2003	Recess milling, drilling and cutting. LEV, water suppression	Lime sandstone *	23	1 - 3 mins	70 - 99%	Not reported
Croteau *et al.*, 2002	Cutting and grinding. Shroud	Concrete (15 - 24%)	75	15 mins	80%	84%
Akbar-Khanzadeh and Brillhart, 2002	Grinding 5 inch grinder, shroud	Concrete*	49	10 -200 mins	77%	74%
Thorpe *et al.*, 1999	Cutting 9 inch & 12 inch angle grinder, water suppression and shroud	Kerbs and slabs, (12 -40%)	12	15 mins	> 90%	50%

* Silica content of material not reported

RCS sampling

Personal respirable dust samples were collected using a Higgins Dewell cyclone (Casella, Bedford, UK.) attached to an air sampling pump (Sidekick pump; SKC Ltd, Dorset, UK.) calibrated pre and post sampling to a flow rate of 2.2 l/min using a primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA). The sampling medium used was 25 mm, 5 µm pore size PVC filters. The Higgins Dewell cyclone and filter cassette was attached to the worker's lapel. A new filter cassette was placed in the Higgins Dewell cyclone for each test carried out and the cyclone was cleaned with compressed air between each test. A different Higgins Dewell cyclone was used for tests carried out with and without a shroud in order to avoid cross-contamination. The silica content of the respirable dust was quantified by X-ray diffraction (XRD) as per MDHS 101 HSE (2005). In addition to the personal samples, a bulk sample of the sandstone used in the trial was submitted for analysis to quantify the percentage silica content of the sandstone. The percentage silica in the bulk sample was quantified by X-ray diffraction. All laboratory analytical analyses were carried out by UKAS accredited laboratory, the Institute of Occupational Medicine (IOM) in Edinburgh, UK. Samples below the analytical limit of detection for crystalline silica were reported as < 0.02 mg and the limit of detection for bulk sample analysis was 0.3%.

Photometric sampling

Photometric data were collected in the worker breathing zone using a Sidepak AM510 personal aerosol monitor (TSI Incorporated, Shoreview, MN, USA) with a Dorr-Oliver cyclone attachment. Prior to use, the photometer was calibrated to the recommended flow rate of 1.7 l/min using a primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA). The photometer had a measurement range of 0.001 – 20 mg/m^3. A different photometer sampling train was used for tests carried out with and without a shroud to avoid cross-contamination. A calibration factor of 3.7 (Healy *et al,* 2013) was applied to the photometric data to accurately estimate the photometric mass concentration for sandstone dust. The Dorr-Oliver cyclone and photometer was fixed to the worker's lapel. All tasks carried out by the worker were observed by the researcher. For tests involving the FLEX grinder, information on the type of grinding wheels used was recorded.

Data analysis

Photometric and RCS data were approximately log normally distributed and the geometric mean (GM) and geometric standard deviation (GSD) of the photometric and RCS data were calculated. Measurements less than the limit of detection (LOD) of the analytical method for RCS were substituted with a constant value of half the LOD (0.01 mg/m^3) using methods described by Hornung and Reed (1990). Using the log transformed respirable dust and RCS data, a student *t*-test was carried out to investigate if there was a statistically significant difference in respirable dust and RCS concentrations when the grinder was used with a shroud and without a shroud. In order to investigate the impact of using different grinding wheels on respirable dust concentrations, general linear regression was carried out using the log transformed photometric data as the dependant variable and after adjusting for the presence or absence of a shroud, grinding wheel and shroud type as the independent variable. All statistical analyses were performed using GenStat software (14^{th} Edition) (VSN International Ltd).

Feedback from workers on use of shrouds

An important aspect of this study was to involve the end user in the exposure control selection process. The researcher collected feedback from the workers by asking them questions regarding the user-friendliness and practicality of the shrouds evaluated. Workers were asked the same questions regarding the shrouds including; the durability of the shroud material, attachment of the shroud to the grinder, cutting of the shroud to expose the grinding wheel, the shroud when it was on the grinder and the operation of the grinder whilst the shroud was in place. The feedback was collected during the trials and from each worker separately. Worker feedback was taken into account in the overall evaluation of each shroud. None of the workers had used any of the shrouds before.

3.4.4 Worker intervention

Very few workplace exposures are controlled by using one control measure alone, and some type of administrative controls are always integrated in an exposure control program. This is done through worker education and training (Goldenhar and Schulte, 1996). The aim of this worker intervention was to increase the worker's knowledge, awareness and skills in order to improve their decision making practises when working with stone.

This part of the project involved the development and administration of a worker intervention questionnaire. The purpose of this questionnaire was to elicit information from OPW stoneworkers on the extent of exposure control usage and identify factors, individual and organisational which influence worker use of exposure controls within the OPW. Results from analysis of questionnaire data allowed identification of individual factors and organisational factors which were then used to develop an educational programme incorporating worker training on hazards associated with RCS, training on RPE and training on the technical intervention. An information booklet in the form of a Concertina card and a display poster for workshops were aso developed. Organisational factors identified were discussed with the OPW.

Worker intervention questionnaire development and distribution

As part of the worker intervention element of the workplace intervention, a questionnaire was developed to collect information on the use of exposure controls and examine factors which influence worker use of exposure controls within the OPW, particularly the barriers to their use. The questionnaire was designed using previous studies in this area (Salazar *et al.,* 1999; IOM, 2002; Jones, 2004; Young, 2007) (Appendix D). The questionnaire consisted of four sections including 14 closed questions, four open ended questions and 44 five-point Likert scale questions. Questions were designed to acquire information on (a) worker demographics; (b) self-reported use of a dust mask/other type of respiratory equipment and other exposure control devices while working with stone; (c) factors which influence worker use of exposure control devices and perceived benefits of using exposure control devices (d) the worker's perceived impact of stone dust on their respiratory health and health effects of working with RCS. The Likert scale questions used agree/disagree statements with scale 1-strongly disagree, 2-disagree, 3-no opinion, 4-agree, and 5-

strongly agree. A pilot of the questionnaire was administered to four stoneworkers from different OPW depots. Amendments were made based on the vgresults of the pilot study.

In each depot, questionnaires with a cover letter were distributed by the depot manager to all stoneworkers who were willing to participate. The cover letter explained the purpose of the study and detailed instructions. The anonymously completed questionnaires were collected from the depots or returned by mail.

Analysis of worker intervention questionnaire

GenStat was used to analyse the data. Descriptive statistics were used to characterise the worker demographics collected in section 1 of the questionnaire. The responses from the five-point Likert scale used to collect data in sections 2 – 4 of the questionnaire, were collapsed into three responses: agree, disagree and no opinion. The responses from the Likert scale were summarised and divided into individual factors outside of the employer's control and organisational factors (factors within the organisation's control).

Development of worker training and hazard communication

Results from the analysis of worker intervention questionnaire data, the exposure assessment and the technical intervention were used to develop an educational program comprising of three training sessions, including training on hazards associated with RCS, RPE and the technical intervention as well as hazard communication tools to supplement the training.

Training on hazards associated with RCS

Worker training on hazards associated with RCS was developed following the training cycle model (FETAC, 2013) which was divided into five stages; training needs analysis, training design, training preparation and delivery, training assessment and training evaluation.

The initial stage of the training cycle involved using the data collected from the worker intervention questionnaires to identify and assess the training needs of the workers and identify what the general content of the training should be. This involved the identification of gaps between the worker's existing theoretical and practical knowledge when working with stone and the required level of theoretical and practical knowledge. The identified training needs of the workers were used to compile a list of learning objectives and ensured that training was appropriate and relevant.

The training (Appendix E) was designed and prepared following the objectives determined in the training needs analysis. Occupational health and safety courses for stoneworkers, for example 'Respiratory health in the workplace: stoneworkers' (HSE, 2012) were reviewed when developing the training materials. Appropriate training methods for each element of the training session were considered. The training was designed by incorporating both instructor led and interactive training methods. Instructor led training was delivered by PowerPoint® presentation and was essential in order to present all of the training content to the workers and to ensure all of the workers received the same information. Interactive methods included quizzes, exercises and question and answer sessions and were designed to keep the training interesting and the workers engaged. The training also included additional visual aids in the form of props and a video clip to further emphasise the key messages of the training.

A pilot of the training was presented to a member of the school of Engineering and Informatics in NUIG and the project supervisor. A member of the OPW Health and Safety Unit, The States Claims Agency and OPW depot managers were invited to comment on the training. The training was amended to reflect any feedback that was received.

The training material included detail on three key areas namely perception of risk, health effects and practical skills/control measures. The perception of risk part of the training included information on respirable crystalline silica, the silica content of different materials and a visual aid in the form of a video demonstrating that respirable dust can be invisible to the naked eye. It also included an interactive session, an activity that required workers to sort pictures of different materials in order of silica content and to discuss their choices. The second part of the training incorporated information on occupational health. The third part of the training focused on specific exposure controls to use whilst carrying out different tasks in the OPW. This part was assembled using exposure measurement data and worker feedback on exposure controls collected during the exposure assessment and technical intervention element of the study as well as the RPE training and fit testing carried out amongst these workers. The hierarchy of exposure controls was explained to the workers, focusing on RPE being bottom of the hierarchy of controls and the specific controls to be used for each task and materials was presented. At the end of the session, workers received a laminated Concertina card (Appendix F) containing all of the key messages from the training session. The purpose of this card was to supplement the training and carry home an information card that the workers could refer to with regards to working safely with RCS dust. The Concertina format was chosen because it was pocket sized and deemed suitable for the work environment in which it would be used. This card included information and images on: respirable crystalline silica, the hazards and health effects of working with RCS and measures for controlling exposure to RCS. The information was tailored towards the OPW stoneworkers especially with regards to which exposure controls to use. A poster for the workplace was also developed to supplement the training (Appendix G), to illustrate the key messages from their training specifically, the exposure controls the workers should use for each stone work task and the correct donning of their RPE.

Pre-training preparations included the development of a presentation session plan. The purpose of the session plan was to help prepare for and deliver the training by clarifying the goals of the training session, detailing the structure and timings of the different elements of the session and identify any resources and special requirements for the training. Pre-training preparations also included the identification of suitable training rooms and availability of resources and participant workers in each of the depots where training was to be carried out. All tools and visual aids required for the training session were prepared.

Once the training was delivered, it was assessed and evaluated to ensure training objectives were achieved and to collect information for the continuous improvement of the training. Assessment and evaluation of the training was applied through two methods; immediate and reaction. The aim of the immediate assessment was to measure if the training delivered the learning objectives to the workers. This was achieved by administering a short questionnaire to the workers to assess knowledge transfer. The questionnaire contained questions on key aspects of the training and was administered to each worker individually followed by discussion of the answers in a group session. The purpose of the reaction evaluation was to collect feedback from the workers via a training evaluation form. Feedback was collected on teaching style, the content of the training, training effectiveness and other relevant feedback. Feedback from the reaction evaluation was used to identify opportunities for improvement of the training.

Training on RPE

Both observational data collected during the exposure assessment and worker intervention questionnaire data indicated that there was a high reliance on RPE to control exposure to RCS in the OPW. Organisation factors identified relating to a poor RPE programme included the allocation of inappropriate RPE, absence of RPE training and fit testing and poor RPE management and maintenance on most sites. In addition to this, personal barriers to RPE usage were identified such as discomfort associated with wearing a poor fitting mask. It was concluded that these issues could be addressed by selecting and fit testing suitable RPE in consultation with the workers and providing them with RPE training. The RPE programme implemented as part of this intervention study contained all the key elements of what constitutes an effective risk control programme involving RPE (Graveling *et al,* 2011). This was carried out amongst all stoneworkers. Workers were offered one of two RPE options; an FFP3 disposable dust mask or for workers with facial hair or who carry out significant quantities of sandstone work, a powered air purifying respirator (PAPR). Three FFP3 dust masks were offered to the workers: 3M™ 8835 P3 valved respirator, 3M™ 9332+ P3 valved respirator and 3M™ K113 P3 foldable valved respirator. A selection of FFP3 respirators models and sizes were offered to the workers so that the respirator was acceptable to, and correctly fitted. The PAPR unit selected was the 3M™ Versaflo powered air system with the 3M™ M-Series M-400 helmet with shroud.

An RPE training presentation programme was developed using the guidelines for RPE training contained in the HSE guidelines 'Respiratory protective equipment at work' (HSE, 2013). Information covered included; why RPE is needed, what are the hazards, the risks and the effects of exposure to RCS, what RPE is being provided and how does it work, why is fit testing required and how to wear and user fit check, store and maintain RPE correctly. The training focused only on RPE offered to the workers to avoid confusion. The training included hands on training on the correct donning of a disposable dust mask and the operation of the PAPR unit. This gave the workers the opportunity to select their preferred RPE. For the workers who selected an FFP3 dust mask, qualitative fit testing was carried out on each worker in accordance with HSE guidance (HSE, 2013).

Training on technical intervention

A training presentation on the technical intervention was developed using exposure data collected during the technical intervention and installation guidelines produced by the manufacturers of the Dustie® shroud, Dustless Technologies. Two different training methods were used; instructor led training in the form of a PowerPoint® presentation and interactive methods including a practical demonstration enabling the participants to ask questions and gain familiarity with the shroud . The practical aspect of the training was aimed at increasing the worker's self-efficiency. Self-efficiency empowers a person to make correct choices and allows them to gain control over personal, social, and administrative forces in order to take action to achieve the desired health behaviour (Israel 1994). Training was led by the author and an OPW engineer, responsible for abrasive wheel training within the organisation. Information covered in the training included; the hierarchy of exposure controls focusing on engineering controls, the results of the technical intervention and justification for the shroud selected, operation of the shroud and step by step theory on the shroud installation. During the shroud installation part of the training, a practical demonstration of the shroud installation was carried out. A question and answer session followed the training which gave workers an opportunity to examine and give their feedback on the shroud.

Post intervention exposure assessment

Post implementation of the Dustie® shroud in the workplace, exposure measurements were taken as per section 3.2., in order to evaluate the respirable dust and RCS exposure levels associated with the shroud under normal working conditions. A sample size power calculation (Equation 3; Rosner, 2011) was used to calculate the number of post intervention samples required (*n*=40).

Equation 3: Sample size power calculation

$$n = \frac{(\sigma_1^2 + \sigma_2^2)\left(Z_{1-\alpha/2} + Z_{1-\beta}\right)^2}{\Delta^2} = \quad \text{Sample size}$$

Where $\Delta = |\mu_2 - \mu_1|$. (μ_1, σ_1^2) = mean and variance of group 1, μ_2, σ_2^2 = mean and variance of group 2, α = significance level, $1 - \beta$ = power

A convenience sampling approach was taken and exposure measurements were collected from five stoneworkers in four depots. Sampling times ranged from 20-40 mins. Workers were asked to carry out their work as normal to ensure exposure measurements were representative of how they usually grind sandstone. This included normal use of all tools, shrouds, vacuum units and RPE. All workers who participated in this study had received RPE training and fit testing, technical intervention training and RCS hazard awareness training. All contextual information associated with the task was recorded.

Tools, accessories and vacuum units used during post intervention sampling

Three hand held electric powered 5 inch grinders were used in during post intervention sampling; a FLEX (Steinheim, Germany) grinder operating at 4500 rpm, a Makita (ANJO-SHI, ACH, Japan) grinder operating at 6500 rpm and a Makita (ANJO-SHI, ACH, Japan) grinder operating at 11,500 rpm.

Over the course of this sampling, the following grinding wheels were used; Diamand Teck (Rathcoole, Dublin, Ireland) Diamond turbo cup grinder, 10 cm and Diamand Teck 12.2 cm Multi cutter diamond cup wheel.

Three different vacuum units were used; A Nederman (Helsingborg, Sweden) L-PAK 250 compact stationary high vacuum unit with a HEPA filter, Hilti's VC20-U portable jobsite vacuum (Schaan, Liechtenstein) and Numatic (Somerset,UK) portable WV-470 commercial vacuum unit.

Post intervention evaluation of worker intervention

Three months after the training, the worker intervention questionnaire (Section 3.4.4) was re- administered to the workers. The purpose of this was to measure the extent to which the worker training influenced worker use of exposure controls. A three month interval was selected based on similar studies (Lambert, 2001; NIOSH, 2004; Young-Corbett, 2012). Questionnaire responses were analysed and compared to questionnaire responses pre-intervention to measure changes in exposure control usage and changes in the factors which influence the workers use of exposure controls. Kruskal-Wallis Analysis of Variance was used to compare the mean differences in participants' responses pre and post intervention.

4.0 Overview of chapter

This chapter contains the results and discussion of results of the research carried out as part of this project, presented as follows: results from the pilot exposure assessment (Section 4.1); results from the survey of Irish stoneworkers (Section 4.2); results from exposure assessment of restoration stoneworkers (Section 4.3); and results from the workplace intervention (Section 4.4)

4.1 Pilot study[1]

In order to design a larger study to investigate determinants of respirable crystalline silica (RCS) exposure amongst restoration stoneworkers, a pilot study was designed and executed to characterise the RCS exposures of a group of restoration stoneworkers engaged in the restoration of historic monuments. The following section contains an overview of the results of the pilot study (Section 4.1.1) and discussion of results of the pilot study (Section 4.1.2)

Pilot study

Worker tasks measured included cutting stone on a water cooled primary saw, cutting stone with 5 inch, 9 inch and 12 inch angle grinders, grinding stone with 5 inch angle grinders, decorating stone with hand and pneumatic chisels and repointing with a trowel. Stone materials worked on included; sandstone, limestone and lime mortar. A local exhaust ventilation (LEV) system was used by the workers for all tasks excluding repointing. This system included one or more extraction arms connected at various locations around the workshop to centralised ducting. The ducting was connected to a Nederman L-PAK 250 compact stationary high vacuum unit.

Table 10 presents the results from the exposure assessment element of this study. 23 personal exposure measurements were taken from 14 workers. A summary of the range of respirable dust and RCS personal exposure data is

[1] The content this Section has been published in: Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2013) Respirable Crystalline Silica Exposures among Stone Workers in Ireland. Silica and Associated Respirable Mineral Particles, STP 1565, Martin Harper and Taekhee Lee, Eds., pp. 39–53, doi:10.1520/STP156520120219, ASTM International, West Conshohocken, PA 201

presented as task concentration, RCS 8-hr time weighted average (TWA) concentration and geometric mean (GM) and geometric standard deviation (GSD) RCS 8-hr TWA concentration grouped by material worked on is presented. RCS exposures for workers working with limestone and repointing with lime mortar (n=14) were all < 0.02 mg/m^3 (8-hr TWA). RCS exposure levels for tasks involving sandstone (n=9) ranged from 0.07 mg/m^3 – 1.7 mg/m^3 (8-hr TWA) with 78% of exposure measurements exceeding the Irish OELV of 0.1 mg/m^3.

Table 10: Summary of the respirable dust and RCS task concentration (mg/m^3) and RCS worker personal exposure concentration data (mg/m^3) expressed as 8-hr TWA

Material	***nm***	***nw***	**Respirable dust task concentration exposure measurement range mg/m^3**	**RCS task concentration exposure measurement range mg/m^3**	**RCS 8-hr TWA exposure measurement range mg/m^3**	**RCS 8-hr TWA GM**	**RCS 8-hr TWA GSD**
Sandstone	9	5	0.70 - 43.4	< 0.1 – 6.3	0.07 – 1.7	0.2	4.8
Grinding angle grinder	4	2	2.6 – 43.4	2.3 - 6.3	1.05 - 1.7	1.38	1.24
Decoration	1	1	1.97	0.2	0.07	-	-
Cutting angle grinder	2	2	0.91 – 2.24	0.47 - 0.66	0.26 - 0.53	0.37	1.6
Cutting water-cooled primary saw	2	2	0.70 – 1.92	< 0.1 - 0.2	< 0.02 - 0.12	0.02	3.6
Limestone	8	3	0.3 – 4.63	< 0.03 - < 0.12	< 0.02	0.006	3.1
Grinding angle grinder	3	1	0.67 – 2.82	< 0.03 - < 0.12	< 0.02	0.002	1.0
Cutting angle grinder	1	1	1.56	< 0.06	< 0.02	0.01	
Decoration	4	2	0.3 – 4.63	< 0.04	< 0.02	0.01	2.6
Lime Mortar	6	6	0.60 -3.37	< 0.04	< 0.02	0.01	1.3
Repointing	6	6	0.60 -3.37	< 0.04	< 0.02	0.01	1.3

nm = number of measurements; total = 23, *nw* = number of workers sampled; total =14

Figures 4 - 5 illustrate examples of real time respirable dust measurements taken with the SidePak photometer. This data was used to investigate respirable dust exposure patterns and to identify work tasks and tools which created high levels of dust. Figure 4 shows the influence of a 5 inch angle grinder on dust exposure when grinding limestone in a partially enclosed workshop, peak aerosol concentrations at 9:21, 11:13, 11:55 and 12:51 are observed when the worker moved away from the capture zone (one hood diameter) of a fixed LEV unit installed in the workshop. The face velocity of this LEV was 10.4 m/s. Figure 5, shows the aerosol concentration during a task involving sandstone cutting using a water cooled primary saw, peak concentrations occurred when the worker moved away from the control panel and closer to the saw to check the cutting line on the stone.

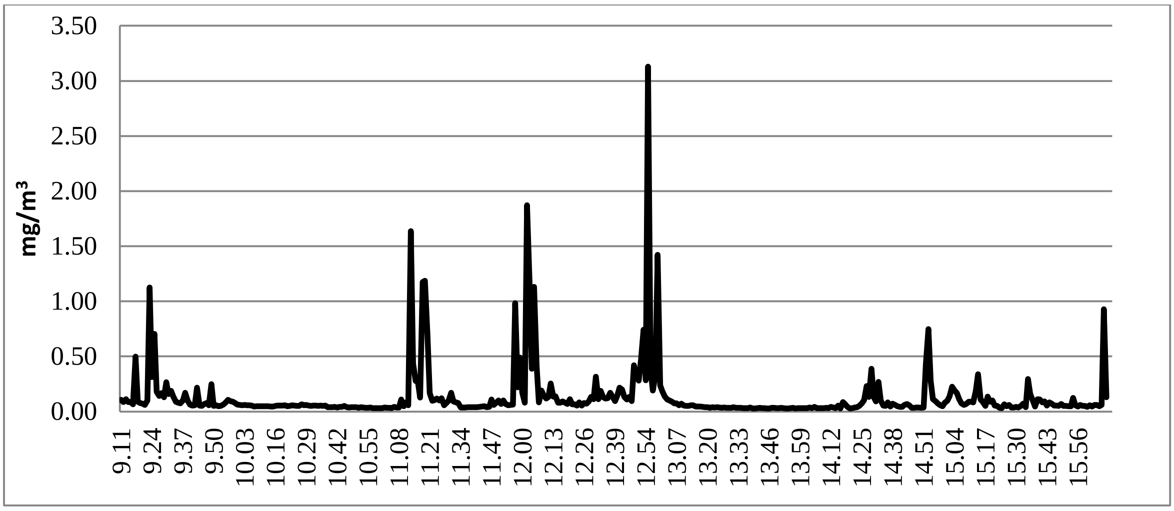


Figure 4: Photometer results for worker grinding limestone with a 5 inch angle grinder

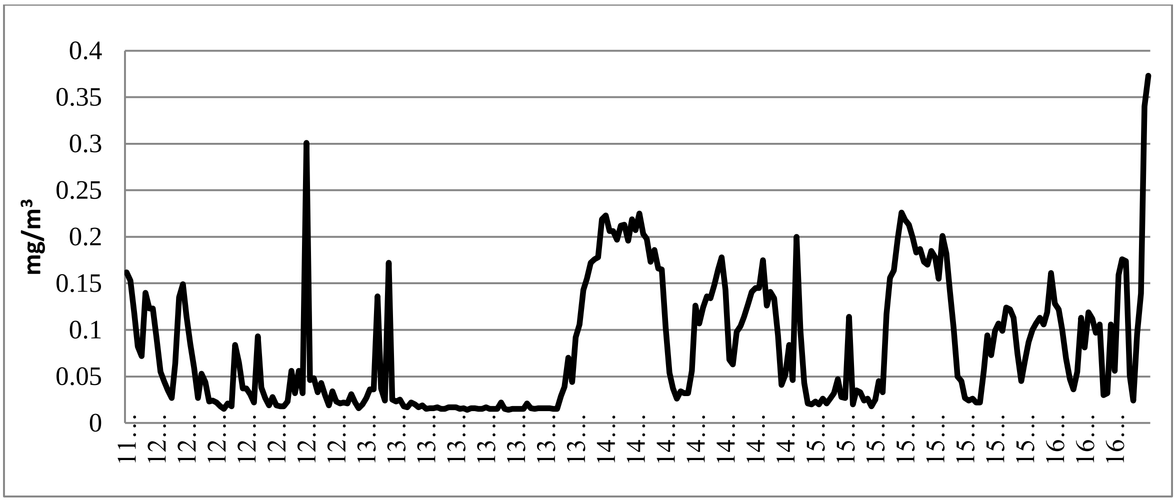


Figure 5: Photometer results for worker cutting sandstone with water cooled primary saw

Discussion of results from the pilot study

Personal RCS exposure measurements were collected from 14 stoneworkers involved in monumental restoration, using sandstone, limestone and lime mortar. Highest concentrations of RCS (0.07 mg/m^3 – 1.7 mg/m^3 8-hr TWA) were found for worker tasks involving sandstone, where 78% of exposure measurements were greater than the OELV of 0.1 mg/m^3. Lowest concentrations (< 0.02 mg/m^3 8-hr TWA) were measured during work with limestone and lime mortar. Exposure concentrations for work involving sandstone and limestone are within the range of those reported in the literature (HSE, 2009) (0.1 mg/m^3 to > 1 mg/m^3, and < 0.1 mg/m^3 respectively). Task exposure concentrations for work with sandstone (< 0.1 mg/m^3 – 6.3 mg/m^3) are comparable to those found by (Seaton and Cherrie, 1998) who reported task concentrations for work involving sandstone in the range < 0.1 mg/m^3 to 8 mg/m^3. The RCS exposures found in this study are higher than those reported for stoneworkers involved in other sectors, for example, granite top fabrication (< 0.04 mg/m^3 to 0.77 mg/m^3 RCS 8-hr TWA) (Simcox *et al.*, 1999), construction/concrete milling and drilling (0.03 mg/m^3 to 1.3 mg/m^3 RCS 8-hr TWA) (Linch, 2002), construction/roofing (0.04 mg/m^3 to 1.21 mg/m^3 RCS 8-hr TWA) (Garcia *et al.*, 2006) and demolition workers (0.03 mg/m^3 – 1.3 mg/m^3 RCS 8-hr TWA) (Tjoe Nij *et al.*, 2003). Respirable dust task exposure concentrations for work with sandstone and limestone ranged from 0.33 - 43.4 mg/m^3 and 0.55 – 4.63 mg/m^3 respectively. Internationally the association between occupational exposure to RCS and the development of silicosis has been well reported (Landrigan, 1986; Rosenman, 1996; Forastiere, 2002). RCS has a steep dose-response relationship; with a reported 2.5% risk of developing silicosis at average daily exposures of 0.1 mg/m^3 RCS (8-hr TWA) over a 15 year period and a 20% risk at exposure concentrations of 0.3 mg/m^3 (HSE, 2006). Exposure concentrations measured here for work involving power tools and sandstone are well in excess of these values. Photometric data was used to supplement exposure measurements and allowed the identification of high aerosol generating work activities. The high exposure concentrations reported in this study can be attributed to the use of materials with a high quartz content, in combination with the use of power tools such as angle grinders, pneumatic chisels and unsuitable exposure controls.

During the exposure assessment, the researcher observed the workers use of exposure controls. Recommended guidance on engineering controls for stonemasonry work involving power tools (HSE, 2006) were not complied with on any of the sites visited. There was a high reliance on respiratory protective equipment (RPE) to control exposure at all sites visited, however the RPE used was not always appropriate and was poorly managed and maintained at most sites. In addition, > 50% of these workers used sweeping as their primary method of cleaning up their work area. This indicates a low level of awareness of the hazards associated with RCS exposure among this group, and highlights a need for training inclusive of information on hazards associated with RCS as well as causes of exposure and suitable exposure controls for stone work. These findings are similar to a study carried out in the UK (HSE, 2009) where it was also reported that engineering controls were not present or inadequate in stonemasonry workshops and that there was still a high reliance on RPE to control high exposures. Some of the work practices observed during this exposure assessment are likely to generate very high concentrations of RCS dust in the workplace, and suggest that many of these restoration stoneworkers are at risk of overexposure to RCS dust. Poor health and safety practice and a lack of awareness of the health risks associated with stone work and exposure to RCS within this sector warrants the need for a larger exposure study and work place intervention for high risk exposure tasks.

4.2 Survey of Irish stoneworkers[2]

In order to collect information on material and tool usage (work practices), the level of health and safety practice, the level of awareness regarding the hazardous effects of RCS and the extent of respiratory illness amongst Irish stoneworkers, a questionnaire survey was designed and administered to a group of Irish stoneworkers. This survey was also carried out in order to investigate the implication of this research for the wider stoneworker community in Ireland, The following section contains the results of the survey of Irish stoneworkers (Section 4.2.1) and discussion of results of the survey (Section 4.2.2)

Survey of Irish stoneworkers

A response rate of 48% (*n* = 63) was achieved to the questionnaire survey. It is suspected that the economic recession, which has greatly affected the buildings business trade in Ireland, was partially responsible for the low response rate. Most of the respondents were male 95% (*n* = 60), between 25 and 64 years old (*n* = 60; 95%). The majority of respondents had been working in the stone trade for 10 to 30 years (71%; *n* = 45), 12% having worked < 10 years and 13% for over 30 years. Among the stoneworkers included, 45% were sculptors (*n*= 16) or worked in stone cladding (*n* =12). A total of 48 respondents reported that they worked with high silica content stone such as sandstone, flint and quartzite of which 87% (*n*=42) used high risk tools such as angle grinders and hand held concrete saws. Participants also identified the control measures and clean up techniques employed by them while using high silica content materials. Table 11 presents a summary of the control measures used by the participants. The most frequently employed control measure was the use of RPE (85%), followed by general ventilation (60%) and on-tool water suppression (37%).

[2] The content of this Section has been published in: Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2013) Respirable Crystalline Silica Exposures among Stone Workers in Ireland. Silica and Associated Respirable Mineral Particles, STP 1565, Martin Harper and Taekhee Lee, Eds., pp. 39–53, doi:10.1520/STP156520120219, ASTM International, West Conshohocken, PA 2013.

Use of local exhaust ventilation (LEV) was low (20%) with only 11 of the respondents reporting using movable extraction arms (*n*=7), on–tool ventilation (*n*=2) or ventilation booths (*n*=1).

Table 11: Use of exposure control measures reported by respondents carrying out work with high silica content materials (*n*=48)

Control Measures	
RPE	*n* = 41 (85%)
General ventilation	*n* = 29 (60%)
On-tool water suppression	*n* = 18 (37%)
Ventilation/capture arm	*n* = 7 (14%)
On-tool ventilation	*n* = 2 (4%)
Ventilation booth	*n* = 1 (2%)

More than half of the respondents (58%) used sweeping as their primary method of cleaning up their work area and almost a quarter of those (24%) judged cleaning up their work area as a task associated with little or no risk.

The questionnaire survey also investigated the stoneworker's knowledge of occupational health and safety and the health risks associated with RCS. Participants in the study were asked to indicate their knowledge of respiratory conditions associated with exposure to silica dust. Of the 63 respondents, 51% had heard of silicosis only. Almost all of the participants reported to have received health and safety training, but less than half of the respondents indicated that the information had not been covered in enough detail or that their training did not include aspects of health and safety related to their work with stone. Only two of the survey respondents reported having received information on silica dust hazards or information on exposure controls. In addition to this, less than half of those who had received training, had received refresher training (39%).

Participants were asked to indicate if they had a company safety policy, workplace risk assessments and safety procedures in place in their workplace. Only 40% of the respondents had all three safety documents in place. Only five workers were aware of the current OELV for RCS. The majority of the participants (74%) reported that they were aware of the National Authority for Occupational Safety and Health in Ireland. A number of guidance documents are published by the Health and Safety Executive (HSE) in the UK aimed at helping employers control the risks posed by stonemasonry dust, 69% of the respondents had not heard of or made use of these documents. Only 36% of the participants agreed that they were well-informed about current health and safety legislation and 46% knew where to access this information.

Only 35% of respondents completed the health section of the questionnaire. They were asked to indicate whether or not they had a work related respiratory illness, whether the illness was self-diagnosed or diagnosed by a doctor and were allowed to select more than one illness. A response rate of 35% was achieved for this question and 27% of these indicated they did not suffer from any work related illness. Six respondents reported having work-related respiratory illnesses as diagnosed by a doctor. Asthma was the most reported of these conditions (n= 4), followed by sinusitis (n=3), nasal irritation (n=2) and persistent cough (n=2). One respondent reported to have been diagnosed with bronchitis and tonsillitis. 52% of the survey respondents reported to have smoked, of whom 13 still smoked.

Discussion of results of survey of Irish stoneworkers

Respondents of the questionnaire survey were largely unaware (69%) of guidance on engineering controls specific to this sector (HSE, 2001) and relied mainly on RPE for exposure control. Only 35% of survey respondents completed the health section of the questionnaire. None of the respondents indicated that they suffered from a long term respiratory illness like silicosis, emphysema or lung cancer. Over the period 2005 – 2011, eight cases of work-related pneumoconiosis attributed to silica have been reported to the Republic of Ireland, Surveillance of Work-Related and Occupational Respiratory Disease scheme and no cases of silicosis or silica related pneumoconiosis were reported to the Irish Occupational Physicians Reporting Activity over the period 2007-2010 (Money, 2012), although it is thought that this is an underestimation of the true number of silica related respiratory diseases in Ireland (Robinson, 2011).

76% of questionnaire respondents reported regularly working with high silica content materials, materials such as sandstone, flint and quartzite which nearly 90% used power tools such as angle grinders and concrete saws. These work practices are likely to generate very high concentrations of RCS dust in the workplace, and suggest that many of these stoneworkers are potentially at risk of overexposure to RCS dust. This is compounded by poor health and safety practice and a lack of awareness of the health risks associated with stone work and exposure to RCS within this sector.

4.3 Exposure assessment of restoration stoneworkers[3]

Following on from the pilot study, a larger exposure study was designed. This study involved characterising the RCS exposures of stoneworkers involved in the restoration of historical monuments in Ireland and to identify workplace determinants of RCS exposure. Results were used later to develop effective workplace intervention strategies to reduce high RCS exposure tasks during restoration activities. This part of the research also involved evaluating the performance of high flow rate samplers for the collection of low concentrations of RCS under restoration stone work field conditions.

The following section contains the results of the exposure assessment of restoration stoneworkers (Section 4.3.1), discussion of results of the exposure assessment of restoration stoneworkers (Section 4.3.2), results of the intercomparison of high flow samplers for RCS measurement (Section 4.3.3) and discussion of results from the intercomparison of high flow samplers for RCS measurement (Section 4.3.4)

Exposure assessment of restoration stoneworkers

Exposure controls walk through survey

All depots contained one stone cutting workshop which contained the following tools; a water cooled primary cutting saw and hand tools including; disc polisher/cylinder polisher, 5 inch, 9 inch and 12 inch angle grinders, pneumatic chisels, hand chisels, brushing tools and hand punches as well as a centralised local exhaust ventilation (LEV) system. The LEV system included one or more movable extraction arms (Nederman Extraction Arm Original) (Nederman, 2010) connected at various locations around the workshop to centralised ducting. The ducting was connected to a Nederman L-PAK 250 compact stationary high vacuum unit. The inlets used on the extraction arms were plastic with a hood diameter of 16 cm. The filtered air was emitted to the external environment through a vent.

[3]The content of this Section has been published in: Healy C, Coggins M, Van Tongeren M, MacCalman L, McGowan P. (2014) Determinants of respirable crystalline silica (RCS) exposure among stone workers involved in stone restoration work. Ann Occup Hyg; 58(1): 6-18

The water cooled primary cutting saw was a bridge saw with a 2 m blade. Water was applied to the blade via a recirculating tank at a rate of 100-120 l/min.

Results of the walk through survey indicated that there were control measures present in all depots but they were regularly misused or inadequate for the task. Recommended guidance on engineering controls for stonemasonry work involving power tools (HSE, 2006) were not complied with on any of the sites visited. A centralised LEV system was present in all depots and although there was evidence of correct installation, this system was purchased without consultation with the workers or consideration of the work processes to be controlled. Issues regarding the use of the LEV system observed in all depots included; the worker not working within the capture zone of the LEV and the capture arm being unable to deal with the high volumes of dust from tasks such as cutting and grinding. The LEV systems in place, although working as per specification (capture velocity 11 m/s, n=12), were not suitable for the processes that were being carried out in the workshop. The tasks of grinding and cutting stone with a 5 inch, 9 inch and 12 inch grinder produced large clouds of dust-laden air too rapidly for it to be captured by the capture arm. Workers regularly worked with large pieces of stone up to 3 metres in length, and it was not practical for the worker to regularly reposition the arm as this involved him stopping the task periodically. Capture arms are not recommended for these work tasks for this reason (HSE, 2001; 2011). RPE was provided in all depots, however, the RPE used by workers varied widely and included nuisance dust masks, positive air purifying respirators (PAPR) and disposable or reusable negative pressure RPE which in the majority of cases, was an FFP3 disposable respirator or half mask respirator with combination filters. Most RPE had an assigned protection factor of 20. However, there was no evidence of a workplace RPE program comprising of training, fit testing and a formal purchasing policy for RPE.

Exposure measurements

A total of 103 exposure measurements were collected from 35 stoneworkers. Sampling times ranged from 30 – 375 minutes with a median sampling time of 240 minutes. Repeated measurements were obtained for 19 workers, with the number of repeated measurements for each worker ranging from 2 – 16. Worker tasks measured included; cutting stone on a water cooled primary saw, cutting stone with 5 inch, 9 inch and 12 inch angle grinders, grinding stone with 5 inch angle grinders, decorating stone with hand and pneumatic chisels and repointing with a trowel. Stone materials worked on included; sandstone, limestone, granite and lime mortar. Respiratory protective equipment was used by workers in 52% of the work tasks sampled. LEV capture hood systems installed were used for all grinding, cutting and decoration tasks carried out in the stone workshops. Water suppression was used as the primary exposure control on the primary saw. Figure 6 provides an example of results obtained with the SidePak photometer, which clearly shows the influence of three different tasks carried out by three different workers (grinding sandstone with a 5" angle grinder in a partially enclosed workshop, cutting sandstone with a 5" grinder in an enclosed work space and repointing with lime mortar outdoors) on the dust exposure. During the grinding task, peaks in the dust measurements were due to the worker working outside of the capture zone of the LEV. During the cutting task, between the periods 11.13 to 11.53, the worker was not actively involved in stonework.

Figure 6: Photometer results for grinding sandstone with 5 inch angle grinder in partial enclosure, cutting sandstone with 5 inch angle grinder indoors and repointing with lime mortar outdoors.

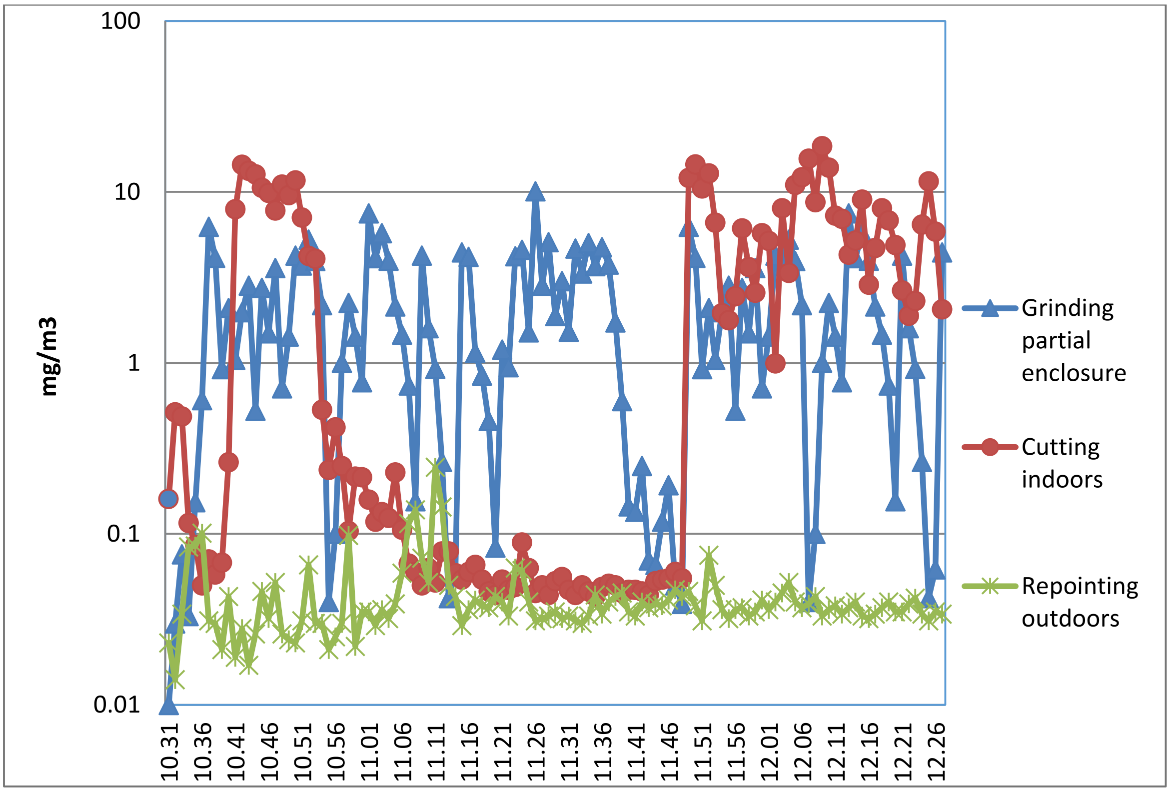


Table 12: Worker personal RCS exposure concentration data (mg/m^3) (8-hr TWA) grouped by material and worker task

Material and Task	*nm*	*nw*	RCS mg/m^3			
			GM[a]	GSD	Range 8hr TWA mg/m^3	Values < LOD
Sandstone	55	14	0.14	10	<0.02[b]-6.00	11
Cutting angle grinder[c]	10	8	0.70	2.2	0.26-1.30	0
Cutting water-cooled primary saw	16	6	0.02	3.9	<0.02-0.13	6
Grinding angle grinder[d]	22	4	0.70	4.5	<0.02-6.00	0
Decoration hand and pneumatic chisel	7	6	0.008	9.0	<0.02-0.07	5
Limestone	15	6	0.008	2.7	<0.02-0.03	13
Cutting angle grinder[c]	1	1	0.01		<0.02	1
Grinding angle grinder[d]	7	3	0.008	1.7	<0.02	7
Decoration hand and pneumatic chisel	7	4	0.007	4.2	<0.02-0.03	5
Lime Mortar	23	17	0.005	2.7	<0.02-0.06	22
Repointing	23	17	0.005	2.7	<0.02-0.06	22
Granite	10	3	0.03	4	<0.02-0.21	2
Cutting water-cooled primary saw	4	2	0.01	4.3	<0.02-0.03	1
Grinding angle grinder[d]	6	3	0.06	2.7	<0.02-0.21	1

nm = number of measurements; total = 103, nw = number of workers sampled; total = 35, number of depots = 6.

[a]Samples below the analytical LOD for crystalline silica are reported as <0.02mg.

[b]GM values are computed from the data including the imputed data for the values below LOD.

[c]Grinding carried out with 5 inch angle grinder.

[d]Cutting carried out with 5 inch, 9 inch and 12 inch angle grinder.

Table 12 presents a summary of the personal RCS exposure levels (mg/m³) (8-hr TWA) grouped by material worked on and task. All active stone work and related activities carried out during the work shift were sampled and therefore 8-hr TWA exposure levels presented are representative of full shift exposures.

RCS exposure for workers working with limestone and repointing with lime mortar (*n*=38) ranged from < 0.02 – 0.06 mg/m^3 (8-hr TWA). RCS exposure for tasks involving granite ranged from 0.02 – 0.21 mg/m^3 (8-hr TWA), 30% of these measurements exceeded the Irish OELV of 0.1 mg/m^3. RCS exposure levels for tasks involving sandstone ranged from < 0.02 mg/m^3 – 6.00 mg/m^3 (8-hr TWA) with 57% of exposure measurements exceeding the Irish OELV of 0.1 mg/m^3. Highest RCS exposure values were recorded for the task of grinding (using a 5" angle grinder) (GM = 0.70 mg/m^3) and cutting (using 5", 9" and 12" angle grinders) sandstone (GM = 0.70 mg/m^3) respectively (Table 12). Lowest RCS exposure values were recorded for the task of repointing with lime mortar (GM = 0.005 mg/m^3).

Table 13 presents the percentage of measurements that exceeded the Irish OELV (0.1 mg/m^3) (HSA, 2011), the occupational exposure standard recommended by the Scientific Committee on Occupational Exposure Limit Values (SCOEL) (0.05 mg/m^3) (SCOEL, 2002) and the threshold limit value (TLV) recommended by the American Conference of Industrial Hygienists (ACGIH) (0.025 mg/m^3) (ACGIH, 2008).

Table 13: Worker personal RCS exposure concentration data (mg/m³) (8-hr TWA) grouped by material compared to Irish OELV, SCOEL recommended OELV and ACGIH TLV for RCS.

Material	**% > 0.1[a] mg/m^3**	**% > 0.05[b] mg/m^3**	**% > 0.025[c] mg/m^3**
Sandstone	57	67	76
Limestone	0	0	7
Lime mortar	0	4	4
Granite	30	40	50

[a] 0.1 mg/m^3 is the Irish occupational exposure limit value (OELV)
[b] 0.05 mg/m^3 is the SCOEL recommended OELV
[c] 0.025 mg/m^3 is the ACGIH Threshold Limit Value (TLV)

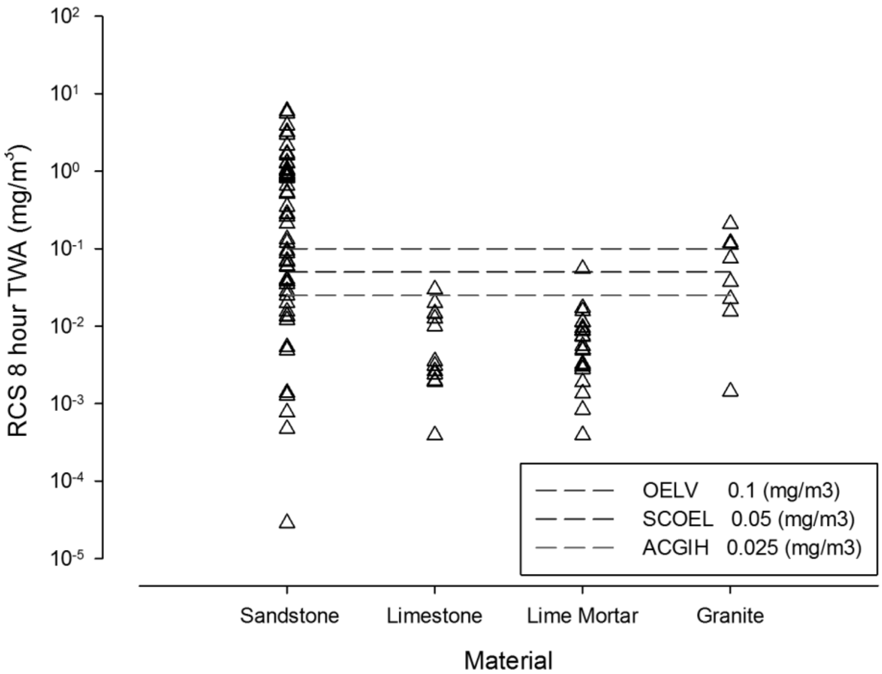


Fig 7: Worker personal RCS exposure concentration data (mg/m³) (8-hr TWA) grouped by material compared to Irish OELV, SCOEL recommended OELV and ACGIH TLV for RCS.

For tasks involving sandstone, 67% and 76% of RCS exposure levels exceeded the SCOEL recommended OELV of 0.05 mg/m^3 and the ACGIH TLV of 0.025 mg/m^3 respectively. 50% of tasks involving granite exceeded the ACGIH TLV of 0.025 mg/m^3 and 7% and 4% of measurements involving limestone and lime mortar respectively exceeded 0.025 mg/m^3 (Table 13 and Fig. 7).

Multiple linear regression and generalised linear mixed regression was carried out to evaluate the relationship between the fixed variables and the log transformed RCS 8-hr TWA concentrations and to investigate the extent of reduction in the between-depot, between-worker (within-depot) and within-worker variance components. Table 14 shows the coefficients of the fixed effects in the optimal model presented as β, SE and Exp (β). Due to the natural nesting of workers within depots, three sources of random variance were investigated – between-depot variability, between-workers within-depot and within-worker variability using mixed effects models (Table 15). After inclusion of the random terms of depot and worker in the model, the fixed effect that was found to be significantly associated with RCS exposure and therefore included in the model was task. Material (granite or sandstone), enclosure, RPE, weather, LEV and task duration were not found to improve the model so were not included. Table 14 illustrates that the tasks of grinding and cutting result in average RCS exposures of between 32 and 70 times the exposures recorded for the task of decorating. No estimate was calculated for the task of repointing as this task was not carried out with sandstone or granite.

Table 14: Coefficients for variables affecting exposure to RCS dust in final mixed effects model of the log transformed exposure to RCS dust among restoration stoneworkers.

	Model 1 (Null Model)		**Model 2 (Model 1 + Task)**		
	β	SE	β	SE	Exp(β)[a]
Intercept	-1.990		-4.46		
Task					
Decorating[b]			0		1
Wet Cutting			0.67	0.06	1.95
Grinding			3.48	0.03	32.45
Dry cutting			4.25	0.18	70.10

[a]Exp(β) is the GM ratio and can be interpreted as the percentage increase in exposure associated with the task (compared with the baseline decorating).
[b]The baseline is decorating

The between-depot, between-worker and within-worker variance components were reduced by 46%, 89% and 49% respectively, after including task in the mixed effects model (Table 15). The between-worker within-depot variance component was reduced from 0.80 to 0.09, after including task in the model, suggesting that the differences in exposure between workers (within a depot) was predominantly due to differences in tasks between the workers.

Table 15: Estimated variance components for the random effects and mixed effects models of the log-transformed exposure to RCS dust among restoration stoneworkers where below LOD values substituted with imputed values.

	Between-depot variance component	Between-worker within depot variance component	Within-worker variance component
Model 1 (Null Model)	1.30	0.80	3.80
Model 2 (Model 1 + Task)	0.70	0.09	1.92

Discussion of results of exposure assessment of restoration stoneworkers

The results of the exposure assessment of restoration stoneworkers are presented in Table 12. The results from this study demonstrate that workers are exposed to very high concentrations of RCS whilst grinding and cutting sandstone and very low concentrations when working with lime mortar and limestone. These results are consistent with the results of the pilot survey where highest concentrations of RCS (0.07 mg/m^3 – 1.7 mg/m^3 8-hr TWA) were found for worker tasks involving sandstone, and lowest concentrations (< 0.02 mg/m^3 8-hr TWA) were measured during work with limestone and lime mortar. While exposure to RCS has been well documented in the mining and construction sectors amongst others, there are limited exposure data for stoneworkers involved in restoration stonework and also for stoneworker tasks involving high silica content materials such as sandstone. Exposure concentrations (< 0.02 mg/m^3 - 6 mg/m^3 RCS 8-hr TWA) are within the range of those reported in the literature by HSE (2009) (< 0.02 mg/m^3 - 7.85 mg/m^3 8-hr TWA). Highest concentrations were reported for grinding and cutting of sandstone with 5 inch, 9 inch and 12 inch angle grinders and lowest concentrations were found for repointing with lime mortar and work with limestone. The RCS exposures found in this study are higher than those reported for stoneworkers involved in other sectors, such as construction/roofing (0.04 mg/m^3 - 1.21 mg/m^3 RCS 8-hr TWA), construction/tuck pointing (0.59 mg/m^3 - 2.84 mg/m^3 8-hr TWA), construction/concrete milling and drilling (0.03 mg/m^3 - 1.3 mg/m^3 RCS 8-hr TWA), demolition workers (0.03 mg/m^3 –

1.3 mg/m^3 RCS 8-hr TWA) and granite top fabrication (0.04 mg/m^3 - 0.77 mg/m^3 RCS 8-hr TWA). The higher concentrations reported in this study are most likely as a result of the high quartz content of the materials used by the workers, i.e. sandstone (33% – > 82% quartz content) and the large aerosol concentrations created during the tasks involving grinding tools with inadequate engineering controls. It was established that exposure control practices were inadequate for the exposures concentrations found in this study. There was a high reliance on RPE to control exposure; however the RPE used was not always appropriate, was poorly maintained and was not face fit tested. The LEV that was present was not fit for purpose, often used incorrectly and was unsuitable for tasks such as grinding and cutting with angle grinders. It was concluded that the current exposure controls in place would not be adequate to reduce exposures to acceptable levels. This was confirmed by the statistical analyses of the data, which showed that the LEV systems currently used in the depots, did not reduce exposure significantly. In Ireland, the occupational exposure limit value for respirable crystalline silica is 0.1 mg/m^3 8-hr TWA (HSA, 2011); a total of 57% of the measurements involving sandstone in this study were well in excess of this value and 67% were in excess of the OELV recommended by SCOEL of 0.05 mg/m^3. Exposure to RCS is associated with a wide range of ill health effects and the RCS levels reported in this study indicate that members of this occupational group are likely to be at significant risk of overexposure whilst carrying out certain tasks. Although SCOEL recommends an OELV of 0.05 mg/m^3, the occupational exposure limit for RCS in Ireland and the UK is 0.1 mg/m^3. There is pressure on regulatory agencies to adopt a lower occupational exposure standard; however, progress on this issue has been hindered by issues related to the reliability of the analytical method at lower RCS concentrations (Stacey, 2007). SCOEL has recommended that, to eliminate silicosis, the OELV for RCS should be below 0.05 mg/m^3; therefore, the exposure concentrations found in this study have the potential to cause serious health problems among the workers exposed. It is envisaged that the OELV recommended by SCOEL of 0.05 mg/m^3 will be included in the European Carcinogens Directive or as a binding OELV in the European Chemical Agents Directive once the analytical challenges associated with measuring these low levels of RCS are addressed (Cherrie *et al.,* 2011). The reduction of the OELV and the strict obligations associated with handling a substance listed in the Carcinogens Directive puts greater emphasis on investigating suitable controls for tasks that consistently generate RCS concentrations at levels above the OELV.

Determinants of exposure

Using multiple linear regression and generalised linear mixed effects regression, exposure data were used to investigate determinants of RCS exposures in order to identify high risk tasks for a future workplace intervention study. In the mixed effects model, task was found to be the only significant ($P < 0.001$) determinant of RCS exposure. Task was also identified as a significant determinant of RCS exposure in the Dutch construction industry (van Deurssen *et al.,* 2014). The fixed variable task explained most of the between-worker variance within a depot. This can be explained by the fact that within a depot, certain individuals are responsible for specific tasks as they are trained on the equipment required to carry out the task. Task also reduced the day-to-day and between-depot variance by 49% and 46%, respectively. The reduction in the between-depot variance could be explained by the specialised nature of the work performed at certain depots during the study for example; due to the availability of a stone cutter, one depot specialised in stone cutting work and another depot focused on repointing a nearby monument. After taking into account the differences in exposure between tasks, the day-to-day or within-worker variance was the largest component followed by the between-depot variance component and the between-worker variance component. Intermittent processes, outdoor work and mobile work have been described as being associated with increased within-worker variability (Kromhout *et al.,* 1993). The remaining within-worker variance could be related to the fact that the majority of stoneworkers in this study are both mobile and working outdoors whilst located on site. Much of the stone work evaluated in this study would also be intermittent, with periods when the worker would be measuring, marking out and moving the piece of stone in between active stone work. Workplace controls, local exhaust ventilation and respiratory protective equipment provided was not adequate for high exposure tasks carried out by these workers. Results from the mixed effects regression analysis indicates that task is a strong predictor of RCS exposure with the tasks of cutting and grinding sandstone associated with very high levels of RCS exposure.

4.3.1 Intercomparison of high flow samplers for RCS measurement[4]

During the exposure assessment study, field trials were conducted in order to evaluate the performance of high flow rate samplers for RCS exposure measurement under the restoration stone work field conditions. This was achieved by carrying out a field trial to measure respirable dust and RCS using three commercially available high flow rate samplers and two reference low flow rate samplers.

Samples were collected on different dates and on real work activities and so the number of sample replicates for the various sample heads and materials differ between Table 16 and Table 17. Work sampled using the 10 mm nylon sampler combinations involved McMonagles Sandstone (60% Quartz), and work sampled using the SIMPEDS combinations involved Killarney Sandstone (33-52% quartz) (Kissane and Pavia, 2008). In many cases the sandstone was damp before use, as it was stored outside, and in some cases (9 of the 19 SIMPEDS trials) the sandstone was pre- soaked by the workers before use. All of the SIMPEDS trials except one (performed outdoors) were carried out in a partially enclosed environment (similar to that shown in Figure 8). Seven out of the 19 trials involving the 10 mm nylon cyclone were conducted outdoors, the remainder in a partially enclosed environment similar to that in Figure 8. Exposure controls used by the workers varied, some wore respiratory protective equipment such as positive air purifying respirators (PAPR), or disposable respirators and used local exhaust ventilation (LEV) in form of a movable extraction arm (Nederman Extraction Arm Original) connected to a Nederman L-PAK 250 compact stationary high vacuum unit was used when available (seven of the SIMPEDS trials and eleven of the 10 mm nylon trials).

[4] The content of this section has been published in: Coggins M, Healy C, Lee T, Harper M. (2013) Performance of High-Flow-Rate Samplers for Respirable Crystalline Silica Measurement Under Field Conditions: Preliminary Study. Silica and Associated Respirable Mineral Particles, STP 1565, Martin Harper and Taekhee Lee, Eds., pp. 125–138, doi:10.1520/STP156520120219, ASTM International, West Conshohocken, PA 2013

Figure 8: Restoration stonemason wearing the FSP-10 paired with the SIMPEDS cyclone, close by on the tripod, CIP10-R/SIMPEDS and GK2.69/SIMPEDS sampler combinations

Exposure concentrations

Average respirable mass concentrations and RCS concentrations collected with high flow rate and SIMPEDS cyclones are presented in Tables 16 and average respirable mass concentrations and RCS concentrations collected with high flow rate and 10 mm nylon cyclones are presented in Table 17.

Table 16: Summary of Average respirable dust concentrations and respirable crystalline silica concentrations collected using CIP-10R, FSP-10 and GK2.69 and SIMPEDS cyclone

Sampler	Task	Material	Number of samples	Sampling time, min	Average respirable dust mass conc (mg/m^3)	Average RCS mass conc (mg/m^3)
CIP-10R	Cutting and Grinding	SS	14	10 - 40	27	15.7
CIP-10R	Grinding	LS	4	30	5.8	0.24
GK2.69	Cutting and Grinding	SS	15	10 - 40	5	3.3
GK2.69	Grinding	LS	4	30	1	< LOD
FSP10	Cutting and Grinding	SS	14	10 - 40	34.2	25.0
FSP10	Grinding	LS	4	30	8.3	0.21
SIMPEDS	Cutting and Grinding	SS	43	10 - 40	40	27.0
SIMPEDS	Grinding	LS	11	30	8	0.47

Notes: SS, Sandstone, LS, Limestone ; < LOD, less than the LOD

Table 17: Summary of Average respirable dust concentrations and respirable crystalline silica concentrations collected using CIP-10R, FSP-10 and GK2.69 and 10 mm nylon cyclone

Sampler	Task	Material	Number of samples	Sampling time, min	Average respirable dust mass conc (mg/m^3)	Average RCS mass conc (mg/m^3)
CIP-10R	Cutting	SS	11	15	32	7.0
CIP-10R	Grinding	LS	8	60	2	0.07
GK2.69	Cutting	SS	11	15	20.8	8.6
GK2.69	Grinding	LS	8	60	1.4	< LOD
FSP10	Cutting	SS	11	15	43.7	12.7
FSP10	Grinding	LS	8	60	6	0.04
10 mm Nylon	Cutting	SS	33	15	14.5	5.0
10 mm Nylon	Grinding	LS	24	60	1.4	< LOD

Notes: SS, Sandstone, LS, Limestone ; < LOD, less than the LOD

A number of samples were removed due to field or laboratory errors (5 samples from Table 16). In general, high concentrations of both respirable dust (5 – 43.7 mg/m^3) and RCS (3.3 – 27 mg/m^3) were collected for all tasks involving sandstone, lower concentrations of respirable dust (1 – 8.3 mg/m^3) and RCS (<LOD – 0.47 mg/m^3) were collected for tasks involving limestone.

The proportion of RCS sampled in the respirable dust are higher for the SIMPEDS combinations than the 10 mm nylon combinations, and there is more variability in the proportion of RCS in respirable dust for the 10 mm nylon trials (0.2 – 0.4, compared with 0.6 – 0.7 for SIMPEDS). Sample data is not compared to the OEL as in some cases, due to overloading of the the high flow sampler filters, sampling was stopped before the end of the work task.

Respirable dust mass concentration and net mass comparison

Average and standard deviation of the respirable mass concentration and net mass ratios of the FSP10, CIP10-R, and GK6.29 to the 10-mm nylon and SIMPEDS cyclones are shown in Table 18.

Table 18 : Respirable dust mass concentration ratio and respirable dust net mass ratio of high flow samplers to 10 mm Nylon and SIMPEDS cyclones

	Reference cyclone	CIP10-R	GK2.69	FSP10
Mass concentration ratio	10 mm Nylon	2.0 ± 0.54 (n=5)	1.4 ± 0.7 (n=16)	1.4 ± 0.73 (n=6)
	SIMPEDS	0.8 ± 0.3 (n=17)	0.4 ± 0.2 (n=4)	11± 0.8 (n=13)
Net mass ratio	10 mm Nylon	12 ± 3 (n=5)	3.5 ± 2 (n=16)	11± 7 (n=6)
	SIMPEDS	3.7 ± 1 (n=17)	0.7 ± 0.3 (n=4)	5.3 ± 4 (n=13)

Quartz mass concentration and net mass comparison

Average and standard deviation of the quartz mass concentration ratios and net mass ratios of the FSP10, CIP10-R and GK6.29 to the 10 mm nylon and SIMPEDS cyclones are shown in Table 19.

Table 19: Quartz mass concentration ratio and quartz net mass ratio of high flow samplers to 10 mm Nylon and SIMPEDS cyclones

	Reference cyclone	CIP10-R	GK2.69	FSP10
Mass concentration ratio	10 mm nylon	1.15 ± 0.7 (n=6)	1.7 ± 0.7 (n=9)	1.24 ± 0.6 (n=6)
	SIMPEDS	1.1 ± 0.3 (n=13)	No data	1 ± 0.8 (n=4)
Net mass ratio	10 mm nylon	7±4 (n=6)	1.6 ± 0.7 (n=9)	8±4 (n=4)
	SIMPEDS	4.5 ± 2 (n=13)	No data	5 ± 2.3 (n=4)

None of the quartz mass concentration ratio data collected for the GK2.69 comparison to the SIMPEDS could be used as the values were less than the LOD (*n*=6), or outliers (< 0.3 (*n*=12) or >3.0 (*n*=1)) and so not included in data analysis.

A scatter plot of quartz mass (µg) collected with high and low flow rate samplers with reference lines of LOD (6 µg) and LOQ (20 µg) is shown in Figure 9. Most of the masses collected with the high flow samplers were above the LOD (CIP10-R, 86 % (*n*=37) FSP10, 84%, (*n*=38)), compared with the low flow samplers (SIMPEDS, 78% (*n*=55); 10 mm nylon, 58%, (*n*=57)). 62% of masses collected with the GK2.69 (*n*=38) were above the LOD. Below LOD values are not indicated on Figure 9.

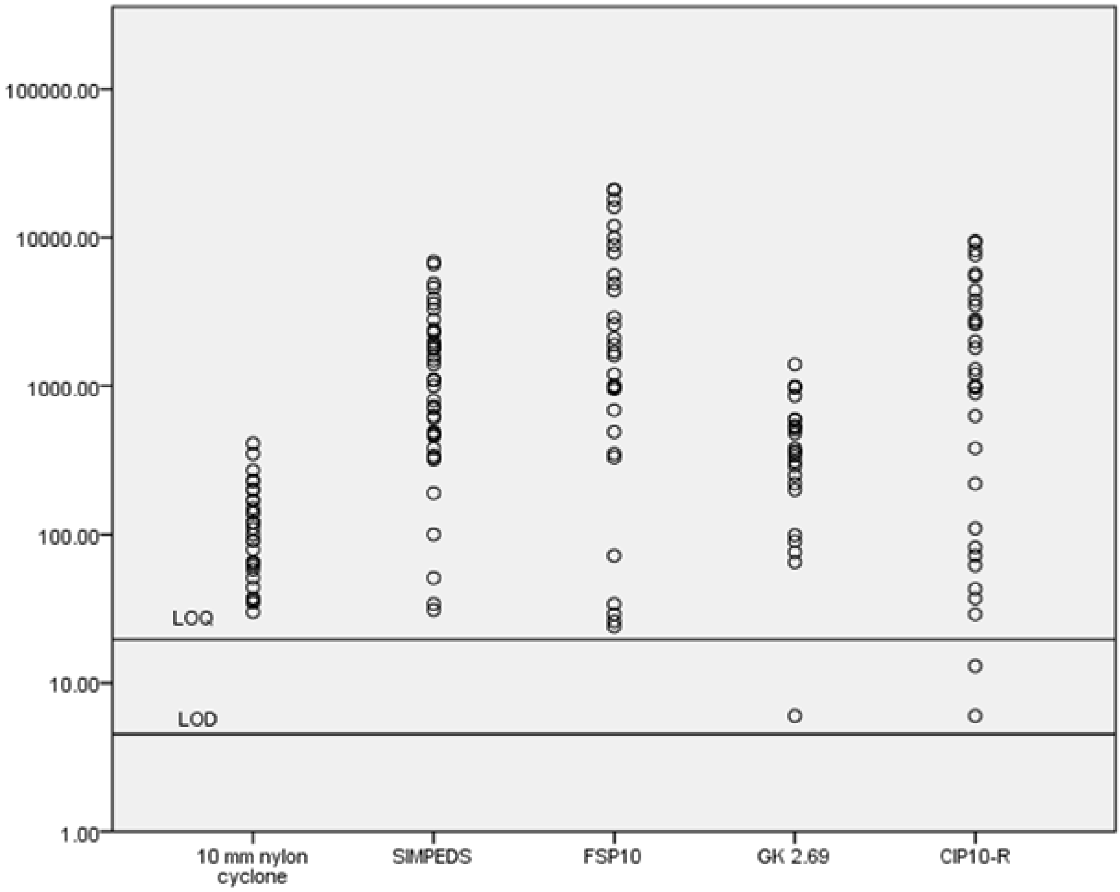


Figure 9: Scatter plot of quartz mass collected with the CIP10-R, GK2.69, FSP10, SIMPEDS cyclone and 10 mm nylon cyclone samplers, showing LOQ of 20 µg and LOD of 6 µg from NMAM 7500.

Practical experience

During the field study, the researcher made some notes regarding the practical use of the sampling equipment. Most of the negative feedback related to the FSP10 and GSA SG10-2 pumps. There was no attachment on the FSP10 to attach the sampler to the worker, workers complained that the FSP10 was very heavy and bulky. The GSA SG10-2 pump was difficult to attach to and remove from the sampling harness and the outlet was in a poor location, which meant that it frequently got blocked during sampling. The workers complained that the GSA SG10-2 pump was very noisy, and that the Legacy pump was very heavy.

Discussion of results from intercomparison of high flow samplers for RCS measurement

The performances of three high flow rate samplers at collecting respirable crystalline silica (quartz) samples in an occupational setting were evaluated in this study. Although this study is impacted by low sample numbers and high standard deviations, some trends are evident in the data and will be discussed here.

The ratio of RCS to respirable dust in samples collected in the SIMPEDS sample pairs are higher than the corresponding ratios for the 10 mm nylon pairs (Table 16 compared to Table 17). Furthermore there was more variability in the ratios calculated for the 10 mm nylon sample combinations. This variation is likely to be as a result of a number of factors, although determining the relative contributions from those factors would require further study. It is likely that there is larger analytical variation in the lower absolute mass of RCS on filters collected in the 10 mm nylon combinations. There is also likely an impact of wind velocity on sampling outdoors, as is evidenced by the slightly higher ratios for the GK2.69 sampler, which has a downward-pointing inlet. Finally the difference in quartz concentrations of the sandstone used in the two trials (33- 52% quartz in the SIMPEDS studies; 60% in the 10 mm nylon studies) likely reflects a difference in grain size of the quartz. Airborne sandstone particles are formed from breaking the cement binding the quartz grains together and it may be that the higher quartz content sandstone had larger grains, thus producing airborne particles perhaps larger than could be sampled in the respirable fraction.

For those sampler pairs where there are more than 11 valid pairs, the average of the respirable mass concentration ratios between the CIP10-R and SIMPEDS, the GK2.69 and 10 mm nylon cyclone, the FSP10 and 10 mm nylon and the FSP10 and SIMPEDS are close to unity (range of results includes 1.0), suggesting that these samplers would be appropriate for sampling respirable dust concentrations during restoration stone work activities. For the other combinations, where the number of valid pairs is less than 11, the results are likely affected by the small sample numbers.

Only two sampler pair combinations had greater than 11 measurements for quartz concentration ratios, but the mass concentration ratios for all combinations that had data (CIP10-R and SIMPEDS and 10 mm nylon; the GK2.69 and 10 mm nylon and the FSP10 and 10 mm nylon and SIMPEDS) were close to unity (range includes 1.0). This suggests that the higher quartz mass collected by the high flow rate samplers did not interfere with the quartz measurements. 86% and 84% of quartz masses collected with the CIP10-R and FSP10 were above the LOD of the analytical method, compared with 78% and 58% of the quartz masses collected with the SIMPEDS and 10 mm nylon. Many of the samples greater than the LOD related to work tasks involving limestone, which indicates that the high flow samplers would be appropriate for sampling RCS concentrations of work activities involving low silica content (< 2%) materials.

4.4 Workplace intervention study

4.4.1 Technical intervention evaluation of shrouds[5]

Effectiveness of shrouds at reducing respirable dust and RCS levels

The task of grinding sandstone was carried out using a 5 inch angle grinder and 6 different grinding wheels, with and without a shroud. A total of 32 photometric and 16 RCS samples were collected when the grinders were used without a shroud. A total of 72 photometric and 36 RCS samples were taken for the shrouds used with the FLEX grinder over three trials. Only eight photometric and four RCS samples were taken for the Hilti shroud during the first trial. Analysis of the bulk sample of sandstone used in the trial determined the sandstone had a silica content of 50.2%.

The concentration of respirable dust was reduced by an order of magnitude when the grinders were equipped with a shroud (*n*=80) compared with grinders without a shroud (*n*=32) (Table 20). Total GM corrected photometric respirable dust levels measured when grinding with a shroud were 0.5 mg/m^3, a reduction of 92% compared to grinding without a shroud (7.1 mg/m^3). Photometric respirable dust exposure reduction for the four shrouds evaluated ranged from 90 to 93%. The FLEX grinder was used with three (FLEX, Dustie®, Dust Muzzle) of the shrouds tested. The Dustie® and Dust Muzzle shrouds demonstrated the highest reduction in geometric mean respirable dust concentrations with exposure levels reduced from 6.1 mg/m^3 to 0.4 mg/m^3 (92% and 93% respectively). A significantly lower ($P < 0.001$) exposure reduction of 90% (6.1 mg/m^3 to 0.6 mg/m^3) was achieved for the FLEX shroud. The Hilti shroud reduced exposure by 91% from 10.4 mg/m^3 to 0.9 mg/m^3 (Table 20).

RCS concentrations were measured (mg/m^3) when grinding with and without a shroud. One sample was below the LOD for silica (0.02 mg/m^3) where no shroud was used. For measurements where a shroud was used, 75% (*n*=30) were below LOD. The RCS concentrations measured were two orders of magnitude lower when the FLEX and Hilti grinders were equipped with a shroud (*n*= 36) compared with grinders without a shroud (*n*=12) (Table 21).

[5] The content of this section has been published in Ann Occup Hyg (2014) doi: 10.1093/annhyg/meu069

The exposure reductions for the RCS concentrations for the four shrouds were slightly higher to that of the respirable dust exposure reductions (Table 21). Total GM RCS concentrations measured when grinding with a shroud were 0.03, a reduction of 99% compared to grinding without a shroud (4.2 mg/m^3). RCS exposure reduction for the four shrouds ranged from 97 to 99%. The Dustie® and Dust Muzzle shrouds demonstrated the highest reduction in geometric mean RCS concentrations with exposure levels reduced by 99% from 3.7 mg/m^3 to 0.01 mg/m^3 and 0.02 mg/m^3 respectively. Due to the high level of non-detects for silica in the RCS data, the confidence intervals in Table 21 are not reliable however it is clear that the RCS concentrations are significantly reduced (P < 0.001) and the proportion of results below LOD are much higher where a shroud was used compared to where no shroud was used.

When the FLEX grinder was used in this study, it was equipped with five different grinding wheels and the Hilti grinder was equipped with one. Photometric respirable dust levels with no shroud in place was highest when using the Diamond turbo cup grinder (11 mg/m^3), Hilti 5 inch diamond grinding cup (10.4 mg/m^3) and Multi cutter diamond cup wheel (10.2 mg/m^3) and lowest for the Corundum grinding point (2.5 mg/m^3). Similarly, the GM silica concentrations (mg/m^3) were highest when using the Diamond turbo cup grinder (1.2 mg) and lowest when using the Corundum grinding point (0.1 mg) when no shroud was in use. The GM photometric exposure levels when a shroud was used were also highest when using the Hilti 5 inch diamond grinding cup (0.9 mg/m^3), Diamond turbo cup grinder (0.6 mg/m^3) and Multi cutter diamond cup wheel (0.5 mg/m^3) and were lowest when using the Corundum grinding point (0.2 mg/m^3). After adjusting for the effect of the shrouds, there was a significant (P < 0.001) difference in photometric respirable dust levels depending on the grinding wheel used (Table 22). Table 22 illustrates that the use of a Hilti 5 inch diamond grinding cup and Diamond turbo cup result in average photometric respirable dust levels of between 3.5 and 2.6 times the respirable dust levels recorded for the Corundum grinding point. Average respirable dust levels produced by the Corundum grinding ring, Multi cutter diamond cup and Velcro diamond disc were 2.3, 2.2 and 1.8 times that of the Corundum grinding point respectively. Type of shroud was added to the model to investigate if the type of shroud used had an effect on the respirable dust levels produced by the different grinding wheels. After adding grinding wheel to the model and adjusting for the effect of the shrouds, the type of shroud did not improve the model and therefore was not investigated further.

Practical Experience

Workers generally indicated that the grinder was easier to use without a shroud especially when working with sandstone. They reported that from their experience, due to its different consistency, limestone dust is emitted from the tool in a more contained cloud and would therefore be more easily captured by a shroud. The primary reason the workers found the grinder easier to use without a shroud was the reduction in visibility when using it however, they did report that cutting the shroud improved this. Transparent shrouds are available to address this problem but are not suitable for work with sandstone. They also reported that the hose attached to the side exhaust port was cumbersome whilst working but that it would not deter them from using the shroud.

Hilti and FLEX shrouds

Although the Hilti shroud reduced photometric respirable dust levels by 91%, it was concluded that this grinder operated at too high a rpm for restoration stone work. The workers did however find the design feature, which enabled the worker to slide the front rim of the shroud to the left in order to cut into corners very useful.

The FLEX shroud was pre-cut which the workers indicated was beneficial as they could see the cutting edge on the stone without modifying the shroud. Also, because the FLEX shroud was constructed of metal, the weight of the vacuum hose did not distort the shroud as it did the other shrouds.

Dustie® and Dust Muzzle shrouds

The workers found that by modifying the Dust Muzzle shroud to cut into corners; it was too flimsy which resulted in the grinding wheel penetrating it. This shroud did not have a cutting line moulded onto it which resulted in the worker judging the cut himself which sometimes resulted in interference with the vacuum holes during use. Furthermore, the Dust Muzzle tended to slip up and down the grinder despite the worker's best efforts to secure it. In the worker's opinion, the Dustie® shroud performed better in terms of practicality. The shroud was described as more durable and robust and this shroud fitted more securely onto the bearing housing of the grinder. The Dustie® had two cut lines molded onto it in order to aid the cutting of it to expose the tip of the grinding wheel, the workers found this facility very beneficial as it also took into account the workers cutting direction preference.

Table 20: Geometric mean (geometric standard deviation) photometric respirable dust concentrations (mg/m^3) measured when grinding with and without a shroud

No Shroud			With Shroud					
Tool	*n*	GM (GSD)	Shroud	*n*	GM (GSD)	Reduction %	*P* value comparison No shroud and shroud	95 % CI
All data	32	7.1 (2.9)	All data	80	0.5 (3.6)	92	< 0.001	0.91 - 0.93
FLEX	24	6.1 (3.2)	FLEX	24	0.6 (3.6)	90	< 0.001	0.87 - 0.92
			Dustie®	24	0.4 (3.1)	92	< 0.001	0.90 - 0.94
			Dust Muzzle Ultra	24	0.4 (4.5)	93	< 0.001	0.91 - 0.95
Hilti	8	10.4 (1.9)	DG-EX 125 Dust extraction hood	8	0.9 (2.3)	91	< 0.001	0.88 - 0.93

Table 21: Geometric mean (geometric standard deviation) respirable crystalline silica concentration (mg/m^3) measured when grinding with and without a shroud

No Shroud				With Shroud						
Tool	Values <LOD	*n*	GM (GSD)	Shroud	Values <LOD	*n*	GM (GSD)	% Reduction	*P* value comparison No shroud and shroud	95 % CI
All data	1	16	4.2 (6)	All data	30	40	0.03 (8)	99	< 0.001	0.97 - 0.99
FLEX	1	12	3.7 (8)	FLEX	7	12	0.07 (12)	98	< 0.001	0.86 - 0.99
				Dustie®	11	12	0.01(3.9)	99	< 0.001	0.98- 0.99
				Dust Muzzle Ultra	10	12	0.02 (6)	99	< 0.001	0.96 - 0.99
Hilti	0	4	6 (1.9)	DG-EX 125 Dust extraction hood	2	4	0.1 (21)	97	< 0.001	-1.78 - 0.99

Table 22: Geometric mean (geometric standard deviation) photometric respirable dust concentrations (mg/m^3) for grinding wheels when grinding with and without a shroud and coefficients for grinding wheels in regression model of the log transformed photometric respirable dust data

Grinding Wheel	No Shroud		With Shroud		Exp(β)*	*P* value
	n	GM (GSD)	*n*	GM (GSD)		
Corundum grinding point*	4	2.5 (3.0)	10	0.2 (2.8)	1.0	< 0.001
Velcro diamond disc	10	5.7 (3.0)	12	0.4 (2.6)	1.8	< 0.001
Multi cutter diamond cup	2	10.2 (2)	20	0.5 (4.0)	2.2	< 0.001
Corundum grinding ring	4	8.6 (1.8)	10	0.5 (2.0)	2.3	< 0.001
Diamond turbo cup	4	11 (2.7)	20	0.6 (4.7)	2.6	< 0.001
Hilti diamond grinding cup	8	10.4 (2.0)	8	0.9 (2.3)	3.5	< 0.001

* The baseline is Corundum grinding point
* Model adjusted for shroud

Discussion of results of technical intervention

Effectiveness of shrouds at reducing respirable dust and RCS levels

The results of this research have demonstrated that respirable dust and RCS concentrations can be significantly reduced by using commercially available shrouds while grinding sandstone with a 5 inch angle grinder in restoration stonework. The short-term respirable dust measurements collected with and without a shroud, indicate that dust levels are reduced by between 90 and 93%. Similar to previous studies with shrouds in place (Akbar-Khanzadeh *et al.*, 2007; 2010; Croteau *et al.*, 2004; 2002; Flanagan *et al.*, 2003; Akbar-Khanzadeh and Brillhart, 2002) we also found concentrations of RCS can still exceed occupational exposure levels (SCOEL Occupational Exposure Limit Value (OELV) of 0.05 mg/m^3; SCOEL, 2002), ACGIH Threshold Limit Value (TLV) of 0.025 mg/m^3; ACGIH, 2008) based on previous exposure assessments (Healy *et al.*, 2014). Previous work (Healy *et al.*, 2014) suggests RCS exposure concentrations of < 0.02 - 6.00 mg/m^3 8-hr Time Weighted Average

(TWA) are produced for the task grinding sandstone using a 5 inch angle grinder. Therefore, in addition to using a shroud, supplemental exposure controls would be required with an assigned protection factor of at least 5 to reduce 8-hr TWA exposures and achieve compliance with the OELV. Reductions in photometric respirable dust concentrations are in agreement with other similar intervention studies (Croteau *et al.,* 2004; Tjoe Nij *et al.*, 2003). Croteau *et al,*. evaluated the effectiveness of different shrouds when grinding concrete on six construction sites. This study reported a mean reduction of 92% in photometric respirable dust levels when using grinders equipped with a shroud. Despite the reduction achieved, 22 and 26% of the samples collected while a shroud was used were greater than the SCOEL OELV of 0.05 mg/m^3 and ACGIH TLV of 0.025 mg/m^3 respectively. Tjoe Nij *et al.*, evaluated shrouds in the construction sector whilst workers carried out recess milling, drilling and cutting of sandstone. This study reported a reduction in photometric respirable dust concentrations of 99% when cutting sandstone with grinders equipped with a shroud. To the author's knowledge, this study is one of a few (Akbar-Khanzadeh *et al.,* 2010) that has investigated the effectiveness of shrouds at reducing respirable dust and RCS levels whilst using a 5 inch grinder with different grinding wheels. Type of shroud was added to the model to investigate if the type of shroud used had an effect on the respirable dust levels produced by the different grinding wheels. After adding grinding wheel to the model and adjusting for the effect of the shrouds, the type of shroud did not improve the model and therefore was not investigated further. The GM of the photometric respirable dust and silica concentration data both when no shroud and shrouds were used were highest for the Hilti 5 inch diamond grinding cup and Diamond turbo cup and were lowest for the Corundum grinding point with average respirable dust levels produced by the Hilti 5 inch diamond grinding cup and Diamond turbo cup 3.5 and 2.6 times the average respirable dust levels produced by the Corundum grinding point. Lowest levels were reported for the Corundum grinding point and Velcro diamond disc. The Diamond turbo cup and Hilti 5 inch diamond grinding cups are all diamond grinding cups and are generally used to remove excess stone and to carry out rough grinding work whereas abrasive tools like the Corundum grinding point are used to add a very fine finish to the piece such as decorative details and grind into corners. Furthermore, the Hilti 5 inch diamond grinding cup and the Diamond turbo cup operated at 11,000 rpm and 4000 – 4500 rpm respectively compared with the Corundum grinding point (3000 rpm). The shroud may not control the stone dust as effectively from grinding wheels operating at a greater RPM due to the dust being emitted at a higher velocity and larger volume. Akbar-Khanzadeh *et al.,* (2010) also reported very high RCS and respirable dust levels when using diamond grinding cups operating at 6000-10000 rpm as did other studies such as Flanagan *et al.,* (2003) who reported a 60% increase in RCS levels when a diamond wheel was employed in comparison to an abrasive wheel. In this study, low levels of RCS and respirable dust were produced when using the Velcro diamond disc grade 50 (an abrasive disc). During the trial, this disc wore out after approximately four tasks, most likely due to the abrasiveness of sandstone which was used in this trial. Based on short term sample data, the overall mean RCS concentration was reduced by the use of a shroud by 99%, similar to that of previous studies that investigated the effectiveness of shrouds for controlling concrete dust during concrete grinding in the construction sector (Croteau *et al.*, 2004; Akbar-Khanzadeh and Brillhart, 2002; Flanagan *et al.,* 2003) and in simulated lab environments (Akbar-Khanzadeh *et al.*, 2010; 2007). These studies reported a 70-92% (Croteau *et al.,* 2004), 67% (Akbar-Khanzadeh and Brillhart, 2002) and 71% reduction in RCS levels (Flanagan *et al.,* 2003). A reduction in RCS concentrations of 99% and 99.7% were reported by Akbar-Khanzadeh *et al.,* (2010; 2007). Despite the exposure reductions achieved by the shrouds in this study, it is important to consider that a lower level of dust control may be achieved by these shrouds when used in an uncontrolled environment. Factors that have been found to affect the effectiveness of shrouds include operator technique (Thorpe et al., 1999) the shroud not being flush with the surface of the material (Collingwood and Heitbrink , 2007; Middaugh *et al.*, 2012) and carrying out edge work (Croteau *et al.*, 2004).

Finally, as demonstrated in previous work, it is important to consider the workers feedback on the shrouds tested. Worker feedback collected during the course of this study suggested that the Dustie® shroud performed best in terms of practicality. For this reason and based on the exposure reduction achieved, the Dustie® shroud was selected as the most suitable shroud for grinding sandstone with a 5 inch angle grinder for this occupational group.

Results of technical intervention post intervention

Post intervention sampling was carried out in order to evaluate the respirable dust and RCS exposure levels associated with the Dustie® shroud post implementation. A total of 40 measurements were collected from five stoneworkers in four depots. Sampling times ranged from 20-40 mins. All tasks involved grinding sandstone using the Dustie® shroud. Four different types of sandstone were used; Leitrim, Liscannor, Roscrea and Old Red sandstone. Two grinding wheels were used; Diamond turbo cup and Multi cutter diamond cup. These grinding wheels were used as they suited the type of grinding required for the piece being worked. RPE with an assigned protection factor of 20 – 40 was worn by all workers during the study and all workers had received all training associated with the worker invention. Workers carried out the task as normal which included active grinding with short periods of marking out, hand chiselling and removing surface dust from stone in between grinding. With the exception of one depot where the workshop was a partially enclosed environment, all measurements were taken indoors

Table 23 presents a summary of the geometric mean (GM) and geometric standard deviation (GSD) of the photometric respirable dust concentrations (mg/m^3) and respirable crystalline silica (RCS) concentrations (mg/m^3) measured when grinding with FLEX and Makita grinders with the Dustie® shroud, post intervention. The total GM photometric respirable dust levels measured when grinding with the Dustie® shroud were 0.3 mg/m^3 ± 4.2 (range 0.004 – 4.45 mg/m^3). 50% of RCS samples (*n*=20) were below the limit of detection (LOD) for quartz (0.02 mg/m^3). Total geometric mean RCS exposure concentrations when the Dustie® was used were 0.5 mg/m^3 ± 2. RCS exposure concentrations were highest in site 1 with measurements ranging from 0.3 – 2.58 mg/m^3 (GM 1.2 mg/m^3) and lowest in site 3 where all RCS measurements were below LOD. GM RCS concentrations recorded in site 2 and 4 were 0.4 (range < 0.02 – 1.06 mg/m^3) and 0.4 (range < 0.02 – 1.67 mg/m^3) respectively.

Practical Experience

During the post intervention exposure assessment, the researcher collected feedback from the various workers regarding their opinion on the user-friendliness and practicality of the Dustie® shroud. Workers generally indicated that the shroud did significantly reduce dust levels whilst they were grinding. The workers however, encountered problems whilst using the shroud to grind along the edges of stone which resulted in the seal of the shroud being compromised, resulting in dust escaping from the front of the shroud. This was particularly an issue where the worker was working on a smaller piece of stone, increasing the amount of time spent preparing stone along edges. The second most reported issue with the Dustie® was the weight of the attached vacuum hose causing the Dustie® to distort and bend upwards, resulting in dust escaping from the front of the shroud. The technique of the worker had an effect on the shroud also. When a worker held the top of the angle grinder handle, this resulted in the shroud being more flush with the surface of the stone, capturing the dust more effectively. If a worker held the bottom of the handle whilst grinding, the shroud had a tendency to bend upwards due to the weight of the hose and caused dust to escape from the shroud.

Table 23: Photometric respirable dust concentrations (mg/m^3) and respirable crystalline silica (RCS) concnetrations (mg/m^3) measured during post intervention sampling.

	n	Values <LOD	GM (GSD)
Photometric respirable dust concentrations (mg/m^3)	40	-	0.3 (4.2)
RCS (mg/m^3)	40	20	0.5 (2)

Discussion of results of technical intervention post intervention

The results of the post intervention sampling suggest that although the Dustie® shroud reduces levels of RCS and respirable dust whilst grinding sandstone with RCS exposure concentrations lower than before the implementation of the shroud, worker technique, tool rpm and the quartz content of the sandstone influences its effectiveness. During the initial evaluation of the Dustie® shroud (Section 4.4.1), RCS exposure concentrations measured were < 0.02 – 1.21 mg/m^3 (GM 0.01 mg/m^3) when grinding sandstone with the Dustie®. The exposure concentrations reported during the post intervention sampling were higher < 0.02 – 2.58 mg/m^3 (GM 0.5 mg/m^3) than those collected during the initial trials. The higher concentrations reported in the post intervention study are most likely as a result of the very high quartz content of the sandstone and the high rpm used by some workers as well as differences in worker practice. RCS exposure concentrations and photometric respirable dust levels were highest in site 1 with measurements ranging from 0.3 – 2.58 mg/m^3 (GM 1.2 mg/m^3) and 0.01 – 4.37 mg/m^3 (GM 0.4 mg/m^3) respectively. The worker in site 1 was grinding Leitrim sandstone with a quartz concentration of > 70% (Kissane and Pavia, 2008) using a Diamond turbo cup at 6000 rpm. Similarly, the highest RCS concentrations recorded during the initial trials were with the Diamond turbo cup (1.21 mg/m^3). In addition to this, the surface of the stone was uneven which resulted in the shroud not being flush with the surface of the stone causing dust to escape from underneath the shroud. The worker was instructed to carry out his work as normal which in this case, resulted in him manually removing excess dust from the stone with a brush between grinding, creating high dust levels. High RCS exposure concentrations were also recorded in site 4 (0.01 – 1.67 mg/m^3) (GM 0.4 mg/m^3) where the grinder was operating at an rpm of 11,500. Lowest RCS concentrations were reported in site 3, where all samples were below LOD. Grinding here was carried out on sandstone with a quartz content of 50% and although grinding was carried out with a Multi cutter diamond cup, it was used at 4500 rpm which resulted in lower RCS and respirable dust exposures. During the exposure assessment, tasks where the angle grinder was operating at a high rpm (6000 – 11,500 rpm) generated a large volume of dust at a very high velocity. In these cases, the Dustie® shroud and the vacuum source being utilised was not capable of completely removing all of the dust generated. For this reason, a purchasing policy should be implemented where angle grinders which operate at a lower rpm or have a variable speed option should be supplied to the workers. Many workers are supplied with angle grinders which operate at a higher rpm because of the quicker rate at which the stoneworkers can produce a finished product. Consequently, using a less powerful grinder may reduce productivity and prove to be a barrier when implementing this purchasing policy. For this purchasing policy to be implemented, management must accept the possibility of a slight reduction in productivity in exchange for an improvement in the working conditions of the stoneworkers. Some studies (Collingwood and Heitbrink, 2007) have indicated that air flow can decrease rapidly during grinding operations and reduce the capture efficiency of the shroud. These is scope for shrouds to incorporate a way for workers to monitor vacuum airflow during operation.

The author's observations in the field indicated that individual worker behaviour had the potential to influence the exposure measurements obtained during the post intervention. Unexplained variances in occupational exposures have been attributed to differences in individual worker's behaviours or work practises (Rappaport *et al.,* 1999; Meijster *et al*, 2008; Goede *et al,* 2012; Davis *et al*, 2014). Differences in worker behaviour have also been associated with between worker variability (Kromhout and Vermeulen, 2001). During the post intervention sampling, the worker's work practises were observed to have an effect on the shroud. Depending on whether the worker held the handle of the angle grinder on the top or the bottom affected the level of dust escaping from the front of the shroud The installation of tool balancers in the workshops would help take the weight off the hose and in turn, prevent the shroud from bending upwards. Additionally, the way in which the angle grinder was held was determined by the worker's personal preference and may not be an easy behaviour to change due to the length of time most of these stoneworkers have been in the trade. These findings suggest that there is scope for a larger behavioural study amongst this occupational group to investigate the association between behavioural determinants of exposure and occupational exposure to RCS. This could be carried out through the application of behavioural models and theories form the social sciences to help explain variance of between worker exposures and encourage safer workplace behaviours (Davis *et al.,*2014).

4.4.2 Worker intervention

As part of the worker intervention, a questionnaire was administered in order to elicit information from stoneworkers in the host organisation on the extent of exposure control usage and identify factors which influence their use of exposure controls. In each depot, questionnaires were distributed to all stoneworkers who were willing to participate.

Questions were designed to acquire information on (a) worker demographics; (b) self-reported use of respiratory equipment and other exposure control devices while working with stone; (c) factors which influence worker use of exposure control devices and perceived benefits of using exposure control devices (d) the worker's perceived impact of stone dust on their respiratory health and adverse health effects associated with working with stone.

A response rate of 67% (*n*=35) was achieved to this questionnaire survey. Most of the respondents were male 99% (*n*=34) and over 36 years of age (83%). 37% of respondents had worked in stone work for 10-20 years (*n*=13), 9% for less than 10 years, 23% having worked 20-30 years and 31% for over 30 years. The responses to questions in each section are described below.

Table 24: Responses to self-reported use of respiratory protective equipment and other exposure control devices while working with stone

Percentage of workers who reported using exposure controls with high silica materials very often to always	63%
Percentage of workers who reported using exposure controls with low silica materials very often to always	71%
Percentage of workers who reported using RPE whilst carrying out stone work Who use negative pressure RPE or PAPR	94%, 96%
Percentage of workers using: Water suppression Receiving capture arm Dustie® shroud	 57% 38% 0%
Person who enforced the use of exposure controls during stone work Supervisor Worker Nobody	 0% 54% 43%

Table 25: Responses to questions regarding the worker's perceived benefit of using exposure controls

Percentage of workers who reported that they use exposure controls to protect their health	94%
Percentage of workers who agreed that exposure controls protected their health now and in the future and decreases their chances of having adverse respiratory symptoms.	82%
Percentage of workers who agreed that using exposure controls now, influences their ability to work in the future	84%

Table 26: Responses to factors which influence worker use of exposure control devices

Main individual factors identified which influence exposure control usage Interference with vision Difficulty communicating with co-Workers Becoming hot while working Causing discomfort Causing glasses/goggles to fog	45% 52% 51% 33% 85%
Percentage of workers surveyed who felt exposure controls took too much time to use.	15%
Percentage of workers indicating that they did not have to purchase their own dust mask for work	97%
Percentage of workers indicating that an apprentice/co-worker sometimes purchases RPE for use in their workplace	3%
Percentage of workers indicating that they had sufficient storage facilities at work to store their RPE.	88%

Table 27: Responses to worker's perceived impact of stone dust on their respiratory health, knowledge of exposure controls, occupational health effects of working with stone.

Percentage of workers believing that they are adequately protected regardless of whether the RPE fits, has been fit tested or if the control device is working properly	12%
Percentage of workers who disagreed that there was no point protecting themselves because they had been exposed to high levels of dust earlier in their careers	80%
Percentage of workers who disagreed that is was too late for them to protect against lung damage	62%
Percentage of workers reporting knowledge of how to correctly; use their recommended exposure control devices how to maintain them how to correctly dispose of them	82% 76% 79%
Percentage of workers agreeing that they were more likely than workers who did not work with stone to develop; lung infections lung diseases	60% 54%
Percentage of workers indicating that they are more likely to use exposure controls when carrying out dusty tasks like grinding	63%

Discussion of results of worker intervention questionnaire

The findings of this questionnaire survey concluded that the educational intervention needed to include a worker training programme including information on hazards associated with RCS and exposure controls as well as hazard communication tools to supplement the training.

The training on RCS hazards focused on; health outcomes associated with RCS exposure, information on high silica content materials and high exposure tasks and exposure controls specifically engineering controls and RPE. Training on the technical intervention focused on background theory regarding the hierarchy of exposure controls focusing on engineering options, the results of the technical intervention and practical hands on demonstration of the new Dustie® shroud.

Since social pressures were not found to have an influence on a worker's choice to use exposure controls, an element on social pressure was not included. The RPE training focused on background theory, RPE selection and use and respirator face fit testing. The training also included a practical demonstration on how to wear, store and maintain RPE correctly. A copy of the training material is included in Appendices F and G.

Assessment of worker training

A training assessment questionnaire (Appendix H) was administered to all workers who attended the training to measure if the training delivered the required learning objectives. The questionnaire contained questions on key aspects of the training and was administered to each worker individually followed by a group discussion. The workers' responses to the training assessment are detailed below.

Table 28: Responses to training assessment questionnaire

Give an example of a task that produces high levels of RCS	
Grinding sandstone	58%
Cutting sandstone	42%
name one occupational disease caused by exposure to RCS	
Lung cancer	10%
Silicosis	90%
Material containing the highest level of silica	
Sandstone	100%
Can RCS dust be invisible to the naked eye?	
Yes	90%
No	10%
Exposure controls that should be used whilst grinding sandstone	
Shroud	72%
RPE	16%
Both Shroud and RPE	33%

Discussion of worker training

The worker training programme successfully delivered the learning objectives to the workers. Worker feedback was positive with most (90%) reporting that they found the training interesting and that they were more knowledgeable after the training about the specific topics covered. They reported that the training style was simple, direct and informative and that the media clip was a very effective communication tool. All of the workers could identify a high silica content material, a high exposure task and an adverse health effect resulting from exposure to RCS. Nearly half (42%) named cutting sandstone as a high exposure task The media clip (Appendix F) demonstrated the fact that small levels of RCS dust can be invisible to the naked eye and proved successful in delivering the message with most (90%) of the workers correctly understanding the core message. The hierarchy of exposure controls was explained to these workers on many occasions focusing on the limitations of RPE as a primary exposure control. Despite this, 16% of workers reported RPE as the only exposure control they should use whilst grinding sandstone. 72% of the workers reported that the Dustie® shroud should be used for grinding sandstone. Only a third (33%) of the workers correctly reported that the shroud and RPE should be used together when grinding sandstone.

Worker intervention questionnaire post intervention

After implementation of the technical intervention and delivery of worker training, the worker intervention questionnaire (Section 3.4.4) was re-administered to the workers after three months. Survey results of the pre and post worker intervention questionnaires were then compared to evaluate the effectiveness of the worker intervention. A response rate of 60% (*n*=31) was achieved to this questionnaire survey. The responses to questions pre and post intervention are described below.

Table 29: Responses to self-reported use of respiratory protective equipment and other exposure control devices while working with stone pre and post intervention

	Pre Intervention	Post Intervention	*P* value
Percentage of workers who reported using exposure controls with high silica materials very often to always	63%	80%	$P < 0.05$
Percentage of workers who reported using exposure controls with low silica materials very often to always	71%	62%	
Percentage of workers who reported using RPE whilst carrying out stone work Who use negative pressure RPE or PAPR	94%, 96%	100% 100%	
Primary engineering control employed by workers Water suppression Receiving capture arm Dustie® shroud	 57% 38% 0%	 25% 9% 9%	
Person who enforced the use of exposure controls during stone work Supervisor Worker Nobody	 54% 43% 0%	 50% 7% 12%	

Discussion of self-reported use of a dust mask/other type of respiratory equipment and other exposure control devices while working with stone post intervention

The intervention yielded some positive outcomes in the worker's self-reported use of a dust mask/other type of respiratory equipment and other exposure control devices while working with stone. At the three month follow-up, there was a significant ($P <$ 0.05) increase in the numbers of workers reporting using exposure controls whilst working with high silica content materials like sandstone. Post intervention, all of the workers reported using recommended RPE, indicating that the worker intervention had been successful. There was an increase in the number of workers using the Dustie®

shroud as their primary exposure control, however, this increase was not significant and water suppression was still the most popular exposure control used. This may be due to the fact that workers were not performing a lot of stone grinding during the period that the post intervention exposure assessment was being conducted. Water suppression is used on the primary saw and on many of the concrete saws within the organisation. Another possible explanation for this low reporting of Dustie® shroud usage post intervention was a shortage of mobile vacuum units and power generators available to many field sites due to budgetary constraints; these are required for the workers to use the Dustie® shroud on site. Also, findings from the post intervention exposure assessment (Section 4.4.3) indicated that some workers had practical issues with the Dustie® shroud and there were underlying behavioural issues which may have hindered its uptake. It is anticipated that use of the Dustie® shroud will increase once these issues are addressed. Three months may have been insufficient time to measure the adoption of a new technology especially given the large number of behavioural issues identified during the post intervention exposure assessment. Other studies on workplace interventions to reduce muscular skeletal disorders amongst floor layers for example (Jensen and Kofoed, 2002) found that workers can be reluctant to accept changes in work practises and new technologies because for a period of time they decreased work intensity and productivity. This study also reported that if workers did not implement the new technologies immediately after their implementation, they would be less likely to use them later. Weidman (2012) in his study on dust-control usage amongst workers in the dry wall finishing industry also reported a low uptake in the use of a new technology three months post intervention and concluded that this is possibly due to the workers not being able to use the new technology immediately after the intervention in their work. This emphasises the importance of refresher training on the technical intervention to remind workers of the availability and potential benefits of the Dustie® shroud whilst grinding stone. Purchasing personal and middle management were found to have a significant influence on decision making regarding new products in a study of the sources of resistance to new technology amongst construction workers (Koebel, 2008). It is also important to remember that interventions might be less effective when an industry is faced with an economic recession because support for occupational health and safety activities decrease (Goldenhar, 2001).

Table 30: Responses to questions regarding the worker's perceived benefit of using exposure controls pre and post intervention

	Pre Intervention	Post Intervention
Percentage of workers who reported that they use exposure controls to protect their health	94%	91%
Percentage of workers who agreed that exposure controls protected their health now and in the future and decreases their chances of having adverse respiratory symptoms.	82%	91%
Percentage of workers who agreed that using exposure controls now, influences their ability to work in the future	84%	83%

Discussion of perceived benefits of using exposure controls post intervention

Workers were still knowledgeable regarding the potential benefits of using exposure controls. These results indicate that the workers are aware of risks associated with stone work.

Table 31: Responses to factors which influence worker use of exposure control devices pre and post intervention

	Pre Intervention	Post Intervention	*P* value
Main individual factors identified to exposure control usage			
Interference with vision	45%	20%	
Difficulty communicating with co-Workers	52%	43%	
Becoming hot while working	51%	54%	
Causing discomfort	33%	21%	
Causing glasses/goggles to fog	85%	79%	
Percentage of workers surveyed who felt exposure controls took too much time to use.	15%	15%	
Percentage of workers indicating that they did not have to purchase their own dust mask for work	97%	95%	
Percentage of workers indicating that an apprentice/co-worker sometimes purchases RPE for use in their workplace	3%	7%	
Percentage of workers indicating that they had sufficient storage facilities at work to store their RPE.	88%	95%	($P < 0.05$)

Discussion of factors which influence worker use of exposure control devices post intervention

Post intervention both positive and negative changes were observed in the individual factors which influence worker's use of exposure controls identified pre intervention. Post intervention, fewer workers reported that exposure controls interfered with their vision and made them feel uncomfortable. Fewer workers reported that using exposure controls interfered with their ability to do their job. Although much effort was employed to include the workers in the selection of the RPE, workers still reported that the use of exposure controls made communication with co-workers difficult, made them hot while working and caused their glasses/goggles to fog. The RPE program implemented as part of this intervention study contained all the key elements of what constitutes an effective risk control programme involving RPE (Graveling *et al*, 2011). Problems are most likely to arise where there is a mismatch between the protection factor of the RPE and perceived risk (which is a strong determinant of attitude to and consequent acceptance of the RPE) (Graveling *et al*, 2011). A selection and worker fit testing programme was set up to address these issues and ensured appropriate RPE was selected for the individual workers, taking into account factors affecting fit such as face shape, facial hair and compatibility with other PPE. The workers were involved in the selection process and although this will help to address the physiological issues that the workers may have with an RPE model, the possibility remains that some workers may find the level of discomfort from a particular type of RPE unacceptable. Based on observations post intervention, many workers continued to don their RPE incorrectly which is a probable cause of these continued issues. This is a similar finding to another intervention study focusing on RPE amongst emergency medical services personnel (Northington *et al.*, 2007) who found poor retention of donning procedures 6 months post intervention. This emphasises the importance of the workers receiving periodic refresher training on RPE.

Table 32: Responses to worker's perceived impact of stone dust on their respiratory health, knowledge of exposure controls, occupational health effects of working with RCS pre and post intervention

	Pre Intervention	Post Intervention	P value
Percentage of workers believing that they are adequately protected regardless of whether the RPE fits, has been fit tested or if the control device is working properly	12%		$P < 0.05$
Percentage of workers who disagreed that there was no point protecting themselves because they had been exposed to high levels of dust earlier in their careers	80%	71%	
Percentage of workers who disagreed that is was too late for them to protect against lung damage	62%	71%	
Percentage of workers reporting knowledge of how to correctly; use their recommended exposure control devices how to maintain them how to correctly dispose of them	 82% 76% 79%	 95% 91% 85%	 $P < 0.05$ $P < 0.05$ $P < 0.05$
Percentage of workers agreeing that they were more likely than workers who did not work with stone to develop; lung infections lung diseases	 60% 54%	 71% 66%	
Percentage of workers indicating that they are more likely to use exposure controls when carrying out dusty tasks like grinding	63%	16%	

Discussion of worker's perceived impact of stone dust on their respiratory health, knowledge of exposure controls, occupational health effects of working with RCS post intervention

There was an increase in worker's perceived risk of stone dust to their respiratory health and knowledge of occupational health issues associated with stone dust post intervention. Results indicate that more participants agreed that they were likely to develop lung damage and specific lung diseases from working with stone. Despite these increases, workers agreed that it was still not too late for them to protect against lung damage. This is possibly as a result of the detailed occupational health information presented to them during the training, delivered by the researcher and an occupational health physician. These findings are not consistent with Weidman (2012) who reported that there was no evidence that an intervention had any effect on increasing perceived health risk or worker health knowledge amongst drywall plasterers. His explanation for the lack of increase in worker health knowledge included that the intervention did not adequately communicate the severity of drywall dust risk and might not have adequately addressed the worker susceptibility to disease from this dust. Post intervention, there was a significant increase in the number of workers who were more informed than before about the importance of correct operation of exposure control devices. There was also significant increase in the number of workers reporting confidence in their ability to correctly use, maintain and dispose of their recommended exposure control devices. This is a similar finding to Hon *et al.,* (2008) in their study of an RPE focused safety intervention which reported that training courses adequately transferred knowledge regarding PPE selection and use. The large practical aspect of the training aimed to increase the workers confidence with regard to exposure controls and possibly led to greater understanding and knowledge retention in these areas. These results are similar to other studies where interventions were found to be effective in increasing hazard knowledge amongst high school students (Lambert, 2001), woodworkers (Lazovich *et al,* 2002), nursing students (Dixit, 2009), farmers (Kim *et al*.,2012) nail technicians (Quach, 2013) and increasing worker self-efficiency among dry wall finishers (Weidman, 2012) and painting contractors (Manterna, 2002).

With regard to the organisational factors investigated, the majority of workers still indicated that they did not have to purchase their own RPE and that sufficient funds were allocated for the purchase of RPE. Significantly more workers reported that sufficient storage facilities were supplied at work to store their RPE. Depot managers were highly involved in the worker intervention which probably resulted in greater storage facilities being made available for the workers, especially for the expensive positive air purifying respirator equipment.

In summary the intervention did not improve all areas such as likely use of an exposure control whilst grinding and some individual factors influencing exposure control usage. It did make significant changes to knowledge of exposure controls and occupational health as well as company and some individual factors influencing exposure control usage. It is recommended that the training be provided on an ongoing basis especially since many of the workers involved who have been working with stone for many years are less susceptible to changing work practises and also, due to the nature of this occupational group where there is often a high worker turnover. Survey results coupled with the author's observations in the field identified some barriers to the success of the intervention. The sites were still commissioning the technical intervention and mobile vacuum units were available at only some of the depots, resulting in the workers on site being unable to use the recommended shroud. Due to previous experience, some of the workers were nervous about disposing of their new negative pressure dust masks with the fear that they would not be allocated sufficient quantities of new ones. Also, in certain depots, workers were not made aware that the Dustie® shrouds were available for their use. Both these issues are managerial issues that are currently being addressed.

The survey findings and observations in the field suggest that there is scope for the use of a behavioural based health and safety programme in conjunction with the technical intervention due to the behavioural issues identified. A recent study in the construction sector indicated that psychosocial factors, for example knowledge and social influence, may play a role in quartz exposure levels when implementing an intervention (Van Deurssen *et al*., 2014). This could be carried out through the application of behavioural models and theories from the social sciences (Davis *et al.*, 2014).

Another possible reason for the slow upatake of the Dustie shroud could be the fact that each worker only received five hours of training altogether as part of the intervention. According to Blooms taxonomy, learning is divided into a number of categories depending on the level of learning achieved (knowledge, comprehension, application, analysis, synthesis, evaluation) (Scott, 2003). Application of knowledge and new skills was the desired outcome of the intervention in this study in order to improve the workers' decision making whislt working with stone. However, the length of training received by each worker may have been insufficient to achieve this. Three months post intervention; workers exhibited a significant improvement in their knowledge of exposure controls and occupational health issues so, remembering and comprehending the training was possibly the actual outcome of the training. It is suggested that one cannot effectively address higher levels of learning outcomes such as application of knowledge until those below them have been covered (knowledge and comprehension) (Atherton , 2013) therefore, a longer period of training may be required to achieve this.

Survey limitations

Three months may have been insufficient time to observe a change post intervention within this occupational group. The sites were still in the commissioning phase of the technical intervention and implementing the requirements of the technical intervention like mobile vacuum units and tool balancers. For example, a large number of powered air purifying respirators were required in some depots which resulted in these depots not purchasing a mobile vacuum unit for use with the Dustie® shroud due to budget restraints. Findings may have been different especially regarding use of the Dustie® shroud had a longer period been left before collecting post intervention data, allowing depots to purchase mobile vacuum units. Also, if a longer period of time had passed, the workers may have carried out more grinding work resulting in the reporting of shroud usage. As with most survey research, this study relied on self-report data which is subjective and may be subject to bias (Steptoe *et al.*, 2010).

Chapter 5: Study Conclusions

5.0 Study Conclusions

Project Conclusions

The specific objectives of this study were to:

- Characterise the respirable crystalline silica (RCS) exposure of a group of stoneworkers involved in the restoration of historical monuments in Ireland.
- To identify and investigate the contribution of determinants of respirable crystalline silica exposure amongst this occupational group and identify specific factors which influence variability in exposure levels within and between workers and depots.
- To design and execute a workplace intervention comprising of technical and worker elements to reduce worker exposure to RCS principally whilst carrying out the task of grinding sandstone within this occupational group.
- To investigate the implication of this study for the wider stoneworker community in Ireland.
- To participate in an international field study to investigate the performance of high flow rate samplers for the collection of low concentrations of RCS under restoration stone work field conditions.

To address these objectives, an exposure assessment was carried out amongst a group of restoration stoneworkers in which RCS exposures and determinants of exposure were determined. Results from the exposure assessment were used to design and execute a workplace intervention comprising of technical and worker elements to reduce worker exposure to RCS.

To address the final two objectives, a questionnaire survey was carried out to investigate the implication of this study for the wider stoneworker community in Ireland. While conducting the exposure assessment at field sites, a short study to evaluate the performance of three high flow rate samplers for the collection of low concentrations of RCS in restoration stonework sites was also performed. Summaries of the main findings of this study are described below.

Objective	Main finding
Characterise the respirable crystalline silica (RCS) exposure of a group of stoneworkers involved in the restoration of historical monuments in Ireland.	The results indicated that restoration stoneworkers were regularly overexposed to RCS dust, especially when working with high silica content materials such as sandstone, 67% of the 8-hr TWA exposure measurements exceeding the Scientific Committee on Occupational Exposure Limits recommended occupational exposure limit value of 0.05 mg/m^3. High RCS exposures were identified for the tasks grinding and cutting sandstone. Tasks involving limestone, lime mortar and granite did not create high levels of RCS. The high exposures reported in this study suggest that these workers are at risk of developing a range of adverse health conditions. This study provides a comprehensive evaluation of exposure to RCS during common activities in restoration stonework, a sector where very little exposure data exists. From an exposure point of view, restoration stone work may be of particular concern due to the materials used, the challenges in implementing traditional exposure control strategies and the large number of workers potentially affected globally. This study contributes exposure data of previously uncharacterised exposure scenarios to the existing knowledge of RCS exposures in the occupational environment. Knowledge of RCS exposures in all potential exposure scenarios is imperative in order to protect the health of workers and aid the design of an effective approach to controlling exposure to RCS. These findings are described in Section 4.3

To identify and investigate the contribution of determinants of respirable crystalline silica exposure amongst this occupational group	This study found task to be significantly associated with RCS exposure, with the tasks of grinding sandstone/granite and cutting sandstone on average 32 and 70 times the exposures recorded for the task of stone decorating. This information was useful when designing the workplace intervention, which focused specially on the worker task of grinding sandstone. This research is the first to identify RCS exposure determinants in restoration stone work and adds to the global body of evidence of determinants of RCS exposure in the workplace. Information such as this is important as it aids the design of workplace interventions to control exposure to RCS. These findings are described in Section 4.3
To identify specific factors which influence variability in exposure levels within and between workers and depots	It was concluded that the RCS exposures varied between and within worker with this occupational group. Task accounted for most of the between-worker and between depot variability but did not have a large effect on the within worker variability. The worker group showed more within worker variability in RCS exposure probably due to the intermittent nature of the stone work projects and the fact that the workers are at times mobile and working outdoors. These findings indicated that the mobile and outdoor nature of the stone work had to be taking into account when designing the intervention. These findings are described in Section 4.3
To design and execute a workplace technical intervention to reduce worker exposure to RCS principally whilst carrying out the task of grinding sandstone within this occupational group.	The Dustie® shroud was found to perform best in terms of effectiveness and practicality and therefore was selected from the technical intervention study. The Dustie® shroud significantly ($P < 0.001$) reduced respirable dust and RCS exposures when grinding sandstone with a 5 inch grinder. Despite this, supplemental exposure controls such as RPE were required to reduce worker 8-hr TWA RCS exposure to below OELVs.

	The respirable dust and RCS levels measured post intervention with the Dustie® shroud were lower than when not using the shroud , but still greater than the OELV This is likely due to the fact that the sites were still in the commissioning phase of the intervention and still purchasing required equipment. Findings indicated that worker behaviour influenced the use of the shroud post intervention. For this reason, it would be beneficial to implement the intervention alongside a behavioural intervention. Further exposure assessments should be conducted twelve months post intervention to further evaluate the effectiveness of the shroud in situ. These findings are described in Section 4.4
To design and execute a workplace worker intervention to compliment the technical intervention to reduce worker exposure to RCS principally whilst carrying out the task of grinding sandstone within this occupational group.	The findings of this questionnaire survey concluded that a worker training program was required which included hazard communication, information on exposure controls and a suitable technical intervention. Three months post intervention; workers exhibited a significant improvement in their knowledge of exposure controls and occupational health issues. Although many individual barriers to RPE usage were addressed by the intervention, some remained post intervention, likely due to worker behaviour. As a result of the organisation still commissioning the intervention, the reporting on shroud use was low. These findings indicate that a longer period should be left after implementation of an intervention to effectively observe a change especially if new equipment has to be purchased as part of that intervention. These findings are described in Section 4.4
To investigate the implication of this study for the wider stoneworker community in Ireland.	Many of the stoneworkers surveyed reported regularly working with high silica content materials and nearly 90% used power tools such as angle grinders and concrete saws with these materials. These findings suggest that the work

	practices carried out in this sector are likely to generate very high concentrations of RCS dust and suggest that many of these stoneworkers are potentially at risk of overexposure to RCS dust. This is compounded further by poor health and safety practice and a lack of awareness of the health risks associated with stone work. These findings indicate that these workers are at high risk of developing silicosis, lung cancer and other illnesses associated with RCS exposure. This research contributes valuable knowledge of the health and safety practises of an understudied group of workers, this information can assist regulatory bodies in the identification of areas that should be targeted in order to improve health and safety amongst this group. These findings are described in Section 4.2
To participate in an international field study led by the Health Effects Laboratory Division, Exposure Assessment Branch of NIOSH to investigate the performance of high flow rate samplers for the collection of low concentrations of RCS under restoration stone work field conditions.	Results showed that high-flow samplers would be appropriate for sampling RCS concentrations in work activities involving low silica- content (< 2 %) materials and would be suitable for testing compliance with a reduced OELV for RCS. The practical issues with regards the high-flow pumps should be addressed since feedback received from the workers indicated that the high flow pumps were not comfortable to wear and could interfere with their work. These findings are described in Section 4.3.1

Chapter 5: Study Conclusions

Research Conclusions

This study is the first to characterise in detail the RCS exposures of restoration stone workers and increases the understanding of the RCS exposures of an understudied occupational group and also identified the need for a workplace intervention study to reduce RCS exposures. This research contributes important exposure information to the international pool of knowledge on RCS exposures, the collection of exposure data from a diverse range of occupations is crucial since no effective treatment exists for silicosis and prevention through exposure control is the only option. Information on different RCS exposure scenarios is important since internationally there are estimated to be millions of workers exposed to RCS in the workplace (Leung, 2012) and although silicosis is no longer a major occupational disease in the developed world, incidences of silicosis are still reported annually in the UK (HSE, 2013). In addition to this, new exposure scenarios continue to arise due to new technology for example fracking where silica sand is used as a proppant to hold open the fissures created by hydraulic fracturing and allow the gas to flow out of the shale into the well (Esswein *et al.*, 2013) and the use of power tools in restoration stone work (Healy *et al.*, 2014). This study demonstrates the significant potential for over exposure to RCS amongst restoration stoneworkers and other stoneworkers who work with high silica content materials worldwide in the construction and restoration of buildings and monuments putting them at risk of developing a range of diseases. Taking into account the number of workers potentially exposed internationally to high levels of RCS and the seriousness of the diseases caused by exposure to RCS, this study provides incentive for health and safety personnel to carry out additional exposure assessments and to design effective approaches to controlling exposure to RCS. This is accentuated by the fact that the EU is in the process of considering an update to the Carcinogens and Mutagens Directive. There is also pressure on industry in the US to control exposure to RCS as it is currently a regulatory concern with OSHA promoting a comprehensive standard on RCS (OSHA, 2013).

In Ireland, the Irish Health and Safety Authority (HSA) has aimed to improve the awareness and management of health and safety amongst small businesses in their annual plan of work 2014. Although there is guidance on hazards associated with stone work available (HSE, 2001; HSA, 2010), the majority of the surveyed stoneworkers were not aware of this guidance and the published guidance gives little information on specific tasks associated with exposure to RCS outside of the construction sector (HSA, 2010) or for specific stoneworker groups, a similar finding to previous studies (HSE, 2010). This research enables a better understanding of the health and safety practises and potential exposure risks of a difficult to reach group of workers. The majority of stoneworkers in Ireland are self-employed or employed in small businesses which are notoriously hard to reach when implementing conventional health and safety initiatives. This study has highlighted a need for more specialised health and safety guidance material within this sector as well as a need for better communication of health and safety guidance, policy and key messages to this sector. A safety awareness campaign promoted in traditional media sources such as newspapers and radio similar to campaigns directed towards the fishing and agriculture sectors could be an excellent way to deliver key safety messages to the stone work sector.

This is the first study to evaluate the effectiveness of shrouds at reducing RCS levels outside of the construction sector and contributes new information to the pool of research on exposure controls to reduce exposure to RCS. This is very important in order to assist professionals in identifying effective controls to reduce exposures. Findings from this study demonstrate that shrouds are an effective engineering control for reducing respirable dust and RCS exposures whilst grinding sandstone during restoration stone work. However, in addition to using a shroud, supplemental exposure controls are required and it is difficult for the worker to monitor flow rate in the system. This indicates that there is scope for further refinement of commercially available shrouds and associated systems especially for activities such as grinding that produce large volumes of dust at high velocities. Results also demonstrate the importance of collecting worker feedback on the practicalities of an exposure control and exposure data should be combined with worker feedback data when selecting an appropriate exposure control for an occupational group, as differences in individual worker behaviour have an influence on the effectiveness of an exposure control. A study of behavioural determinants of exposure amongst this study population should be carried out with the aim of improving workplace intervention design.

The worker element of the workplace intervention showed that the intervention was successful in improving some aspects of worker exposure control usage and health and safety knowledge whilst working with stone but not successful in other areas predominantly the use of the shroud. If post intervention sampling was conducted one year after implementing the intervention, the outcome could be different given the

organisation was still commissioning the intervention when the post intervention sampling was performed. This study demonstrates the challenge posed by implementing an intervention in difficult economic circumstances where an organisation may not have the finances to implement an intervention in a short period of time. This is an important consideration that should be taken into account in future studies investigating the effectiveness of technical interventions in the workplace.
To meet the emerging needs for precise measurement of low concentrations of RCS for shorter sampling periods, collaborative work was carried out to evaluate the effectiveness of high-flow rate samplers for RCS measurement in restoration stone work. This study found that high-flow-rate samplers are appropriate for sampling RCS during restoration stone work and are suitable for quantifying exposures, even with low silica materials for short term samples. These findings contribute to an international dataset on the effectiveness of these samplers in different occupational environments and provide valuable data to aid the establishment of a suitable method of measurement to support enforcement activity of a lowered OELV. Despite the effectiveness of the high-flow samplers, there were some issues with their practicality and the importance of collecting worker feedback to assess the samplers' practical use in the field was demonstrated. If these high-flow samplers are to be adopted as a primary method of measuring low concentrations of RCS in the workplace, emphasis must be placed on making them more comfortable to wear for the worker.

Limitations of study

- Whilst this research was carried out in one organisation, the materials, tools, exposure controls and work practises used by the study population are comparable to other restoration stoneworkers and stoneworker groups.
- In this study, three months may have been insufficient time to observe a change post intervention within this occupational group. The sites were still in the commissioning phase of the technical intervention and not a lot of grinding work was being carried out in the three month period.
- Both the survey of Irish stoneworkers and worker intervention questionnaire in this study relied on self-report data which is subjective and may be subject to bias.

Recommendations for future research

- Due to the lack of exposure data available for restoration stonework and work with high silica content materials, more detailed exposure assessments with corresponding contextual information should be carried out in these areas to provide further insight into the exposures of these workers.
- This study has highlighted that the larger stoneworker community in Ireland are likely to be at risk of overexposure to RCS dust. Information and guidance material should be developed and an effort should be made to deliver key messages regarding hazards associated with stone work to this traditionally hard to reach sector.
- Higher concentrations of dust and RCS post intervention are possibly attributable to differences in individual worker behaviour and there is scope for a study of behavioural determinants of exposure amongst this study population with the aim of improving intervention design.
- An exposure assessment amongst this occupational group should be conducted one year post intervention to measure RCS concentrations and to further assess the effectiveness of the intervention.
- Due to the elevated exposures found in this study, there is scope for an investigation into the secondary RCS exposures of bystander workers working within the facility of the restoration stoneworkers.
- There is scope for technical and practical improvement to commercially available shrouds especially for activities such as grinding that produce large volumes of dust at high velocities.
- Further evaluations of high-flow samplers in real occupational environments should be conducted to further validate results from laboratory studies and to evaluate practical issues such as pump weight.

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Appendix A: Peer reviewed papers

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Determinants of Respirable Crystalline Silica Exposure Among Stoneworkers Involved in Stone Restoration Work

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Objectives: Crystalline silica occurs as a significant component of many traditional materials used in restoration stonework, and stoneworkers who work with these materials are potentially exposed to stone dust containing respirable crystalline silica (RCS). Exposure to RCS can result in the development of a range of adverse health effects, including silicosis and lung cancer. An understanding of the determinants of RCS exposure is important for selecting appropriate exposure controls and in preventing occupational diseases. The objectives of this study were to quantify the RCS exposure of stoneworkers involved in the restoration and maintenance of heritage properties and to identify the main determinants of RCS exposure among this occupational group.

Methods: An exposure assessment was carried out over a 3-year period amongst a group of stonemasons and stone cutters involved in the restoration and maintenance of heritage buildings in Ireland. Personal air samples (n = 103) with corresponding contextual information were collected. Exposure data were analysed using mixed-effects modelling to investigate determinants of RCS exposure and their contribution to the individual's mean exposure. Between-depot, between-worker, and within-worker variance components were also investigated.

Results: The geometric mean (GM) RCS exposure concentrations for all tasks measured ranged from <0.02 to 0.70 mg m^{-3}. GM RCS exposure concentrations for work involving limestone and lime mortar were <0.02–0.01 mg m^{-3}, tasks involving granite were 0.01–0.06 mg m^{-3}, and tasks involving sandstone were <0.02–0.70 mg m^{-3}. Sixty-seven percent of the 8-h time-weighted average (TWA) exposure measurements for tasks involving sandstone exceeded the Scientific Committee on Occupational Exposure Limits recommended occupational exposure limit value of 0.05 mg m^{-3}. Highest RCS exposure values were recorded for the tasks of grinding (GM = 0.70 mg m^{-3}) and cutting (GM = 0.70 mg m^{-3}) sandstone. In the mixed-effects analyses, task was found to be significantly associated with RCS exposure, with the tasks of grinding and cutting resulting in average exposures of between 32 and 70 times the exposures recorded for the task of stone decorating. The between-depot, between-worker, and within-worker variance components were reduced by 46, 89, and 49%, respectively, after including task in the mixed effects model.

Conclusions: Restoration stoneworkers are regularly overexposed (compared with 0.1 and 0.05 mg m^{-3} 8-h TWA) to RCS dust when working with sandstone. The results indicate that the tasks of cutting and grinding sandstone are predictors of increased exposure to RCS dust. In order to decrease exposure to RCS, efforts should be focused on developing and implementing interventions which focus on these high-risk tasks.

Keywords: determinants of exposure; exposure assessment; silica exposure

INTRODUCTION

Crystalline silica is an abundant mineral in the Earth's crust and is present in varying amounts in almost all rocks, clays, and sands. Exposure to respirable crystalline silica (RCS) is therefore possible when these materials are worked and can lead to a range of adverse health effects depending on the magnitude of exposure. The most widely reported health effect associated with exposure to RCS is silicosis (Landrigan *et al.*, 1986; Rosenman *et al.*, 1996; NIOSH, 1999; Forastiere *et al.*, 2002). Other health effects include lung cancer (IARC 1997; Siemiatycki *et al.*, 1989), stomach cancer (Siemiatycki *et al.*, 1989), a range of autoimmune diseases such as systemic sclerosis (Sluis-Creamer *et al.*, 1985; Englert *et al.*, 2000), rheumatoid arthritis (Stolt *et al.*, 2005), chronic and subclinical renal disease (Steenland *et al.*, 1990, 1992; Hotz *et al.*, 1995; Steenland and Goldsmith, 1995), and cardiovascular diseases (Chen *et al.*, 2012). There is also evidence that workers exposed to silica are at an increased risk of mycobacterial infections of the lungs (Corbett *et al.*, 1999) and chronic obstructive pulmonary disease (Oxman *et al.*, 1993).

Workplace exposure to RCS is well documented in many industries including construction (Pannell and Grogin, 2000; Lumens and Spee, 2001; Garcia *et al.*, 2006; Heitbrink and Bennett, 2006; Echt and Sieber, 2007; Miscetti *et al.*, 2011; Middaugh *et al.*, 2012), roofing manufacture (Fayerweather *et al.*, 2011), the heavy clay industry (Love *et al.*, 1999), potteries (Cherry *et al.*, 1998), the industrial silica sand industry (Brown and Rushton, 2005), agriculture (Archer *et al.*, 2002; Swanepoel *et al.*, 2011), exploration of natural resources (hydraulic fracking; Napoli, 2012), and construction stone masonry (Guénel *et al.*, 1989; Tharr and Lofgren, 1993; Cain, 2009; HSE, 2009). However, few studies (Seaton and Cherrie, 1998; HSE, 2009) have evaluated personal RCS exposure among restoration stoneworkers working with high silica content materials such as sandstone.

Restoration stone masonry can be distinguished from construction stone masonry by the use of tools and techniques specific to restoration work (Caroe and Caroe, 2001; English Heritage, 2012). Their work regularly involves the application of fine decorative detail to stone, which often requires the worker to work in very close proximity to the exposure source. Restoration stoneworkers are also required to follow strict conservation guidelines and therefore not permitted to substitute high silica content materials with low silica alternatives. Sandstone was widely used in Europe as a construction material down through the centuries. In Ireland, the Normans (11–12th century) regularly used sandstone for dressings and carvings as it was easily quarried and a highly favoured building material. It has been used for centuries in roofing, flooring, and the construction of dry stone walls. In the restoration of these buildings today, it is common architectural practice to use the stone from the quarry which supplied the original stone, or a stone with similar properties (Galán *et al.*, 1999; Fitzner *et al.*, 2003; Bolton, 2006; Steinbauer *et al.*, 2012).

Sandstone is a sedimentary rock with an average quartz content of 82% (w/w) or higher (Carmichael, 1989; Kissane and Pavia, 2008). Airborne RCS concentrations are related to the quartz content of the rock being worked (Guénel *et al.*, 1989; Kullman *et al.*, 1995) and therefore stoneworkers carrying out work on sandstone are potentially exposed to excessive levels of RCS. Research by Seaton and Cherrie (1998) on workers involved in the restoration of a sandstone cathedral in Scotland and the UK baseline silica survey (HSE, 2009) suggest that RCS exposure for this occupational group could regularly be in excess of the workplace exposure limit in the UK of 0.1 mg m^{-3}. Furthermore, the findings of the UK's baseline survey on RCS exposure suggest that engineering controls are often absent or inadequate for this type of work. A pilot study investigating RCS exposures among restoration stoneworkers (Healy *et al.*, 2013) found high exposures to RCS were frequently experienced by this group. This warrants a more detailed investigation of RCS exposures in this group particularly for high-exposure tasks. The further characterization of the RCS exposures for this occupational group is imperative in order to design an effective approach to control exposure to RCS. Knowledge of the main determinants of RCS exposure will aid the design of an effective approach to control exposure to RCS in restoration stonework. Previous studies found that material worked on, task, equipment, trade, job site, work area (indoors/outdoors), cross draft, and engineering controls to be important determinants of RCS exposure in the construction sector (Lumens and Spee, 2001; Bakke *et al.*, 2002; Flanagan *et al.*, 2006; Sauvé *et al.*, 2012). The objectives of this study were to characterize the RCS exposures of stoneworkers involved in the restoration of historical monuments in

Ireland and to identify workplace determinants of RCS exposure. These results will be used to develop effective workplace intervention strategies to reduce high-RCS-exposure tasks during restoration activities.

MATERIALS AND METHODS

Study population and site description

The study population consisted of 35 restoration stoneworkers employed with the Commissioners of Public Works Ireland, responsible for managing, maintaining, and restoring over 740 of Ireland's national monuments. Worker participation was voluntary, and subjects were recruited in coordination with the organization's Health and Safety unit and depot managers.

The stoneworkers were located in six centralized depots and associated historic monuments around Ireland. During this study, workers worked on sandstone, limestone, lime mortar, and granite. The tasks carried out and the materials used in a depot at any one time were dependent on the materials and the type of restoration required for the monument under restoration. Minor restoration of a monument only involved repointing, but major restoration required restoration and/or construction of existing or new sections of the monument. The stoneworkers worked in a stone cutting workshop located in the depot or on site at the monument under restoration depending on the task they were carrying out. Within the group restoration stoneworkers, two main job titles could be distinguished based on their job specifications: stone cutter and stonemason (Table 1). Each depot had an average of one stone cutter and seven stonemasons (range: 1–17).

Walk-through survey

Prior to the commencement of the study, the researcher met with depot managers and workers and presented an overview of the project objectives and proposed sampling protocols. Study participants were asked to complete a self-administered questionnaire, designed using information gathered during preliminary site visits and previous research in this area (HSE, 2001, Lumens and Spee, 2001; Flanagan *et al.*, 2003; HSE, 2006, 2009). The purpose of this questionnaire was to collect information on the tasks, specific tools, materials, and clean-up methods frequently used by the worker in order to develop a contextual information sheet for field sampling. This field sheet was used to collect detailed contextual information during the measurement period including details about the task, tools, materials, exposure controls, respiratory protective equipment (RPE) and other information the author deemed important to record.

At the beginning of the study, a visual assessment was carried out in each of the stone cutting workshops using a checklist to collect detailed information on exposure controls used. This checklist was developed with reference to similar studies (HSE, 2006; Renton *et al.*, 2010) and collected information on the following: design of local exhaust ventilation (LEV) system, maintenance and effectiveness of the LEV including capture velocity, worker use of LEV and RPE, and cleaning and housekeeping practices.

Sampling methodology

Samples were collected using an air sampling pump (Sidekick pump; SKC Ltd, Dorset, UK.) with Higgins Dewell cyclone (Casella, Bedford, UK.) and 25 mm, 5 µm pore size polyvinyl chloride

Table 1. Description of job specifications of stoneworkers included in study.

Job title	Job specification
Stone cutter	A stone cutter specialises in cutting stone. The majority of stone cutting is carried out in a workshop. In the workshop, this involves cutting quarried stone to the rough size required for the finished piece, using a water cooled primary saw. If further significant cutting is required on site, a stonecutter uses a 5″, 9″, or 12″ angle grinder.
Stonemason	A stonemason performs several tasks including the shaping of stone to the exact geometrical shape required for the finished piece, normally using a 5″ angle grinder, addition of decorative detail to the finished pieces with hand and pneumatic chisels, arranging the resulting finished pieces in the monument and removing deteriorated mortar from a monument before repointing with new mortar. A stonemason carries out the majority of his work on site and rarely in the workshop.

filters pre-calibrated to a flow rate of 2.2 l min^{-1} with a primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA). The sampling pump was attached to a belt around the waist or to a harness. The cyclones were attached to the worker's lapel within 30 cm of his breathing zone, ensuring the cyclone inlet was in a downward vertical position. Workers were asked to perform their work tasks as normal to ensure that the dust levels measured were representative of normal work activities. This included normal use of all tools, engineering controls, and RPE. Task sampling was performed, and when sampling a work task, all preparatory work i.e. marking out of stone, positioning of stone, the work task, and all clean-up activities after the task were monitored. Workers typically only performed one single task per work shift.

The respirable dust samples were analysed gravimetrically according to HSE MDHS 14/3, and the RCS content on the filter was quantified by X-ray diffraction as per HSE MDHS 101. All laboratory analytical analysis was carried out by the Institute of Occupational Medicine in Edinburgh. Samples below the analytical limit of detection (LOD) for crystalline silica were reported as <0.02 mg.

In addition, real-time dust measurements were carried out using a SidePak AM510 personal aerosol monitor (TSI Incorporated, Shoreview, MN, USA) adjusted to measure respirable dust using a 10 mm Dorr-Oliver cyclone attachment. The SidePak AM510 was calibrated to the recommended flow rate of 1.7 l min^{-1} using a primary air flow meter (DryCal DC Lite; BIOS International, NJ, USA.) and was set to log data at 1-min intervals. The data were downloaded to a computer using TSI Trackpro software. Results of the SidePak were used to examine exposure patterns whilst different tasks were carried out and to identify tools and tasks which created high levels of dust.

Statistical analysis

Task-specific exposure data were expressed as 8-h time-weighted average (TWA) concentrations. It was assumed that the RCS exposure for the remainder of the work shift was zero for the following reasons: the worker was carrying out non-stonework activities such as driving a fork-lift or transporting finished stone pieces to the monument, and the worker being monitored was working away from the stone workshop or any colleagues carrying out stonework. The exposure data were approximately log normally distributed and the geometric mean (GM) and geometric standard deviation of the 8-h TWA average exposure data were calculated.

For testing compliance with the Occupational Exposure limit value (OELV) the joint document by the British and Dutch occupational hygiene societies (BOHS and NVvA) on 'Testing Compliance with Occupational Exposure Limits (OELs) for Airborne Substances' (BOHS, 2011) was followed. Exposure data were categorized into similar exposure groups based on material and task and compliance was estimated by comparing the 95th percentile of the exposure distribution with the OELV (BOHS, 2011).

In order to investigate determinants of RCS exposure and their contribution to the individual's mean exposure, mixed-effects modelling with forward inclusion of the variables was carried out using the log-transformed RCS 8-h TWA data for materials granite and sandstone (n = 65) as the dependant variable. RCS 8-h TWA data for materials limestone and lime mortar were not included in the model because of the large number of non-detect data. Material worked on, worker task, RPE, LEV, job title, weather, level of enclosure, and task duration were introduced as fixed variables, and three sources of random variance were looked at—between-depot variability, between-workers within-depot variability, and within-worker variability. RPE and LEV each had two levels depending on whether they were present or not. Enclosure had three possible levels (indoors, outdoors, and partial enclosure), while weather was grouped into six levels (wet and windy, dry and windy, wet and still, dry and still, showers and damp, and sunny). Forward stepwise regression was used to introduce variables significant at the $P \le 0.001$ level one at a time. Variables were added until no improvement to the model was made. The results of the regression modelling were reported as β, SE and Exp(β). β is the coefficient of the fitted line from the regression modelling, and SE is the standard error of the estimated β. As the regression modelling was carried out with data on the log scale, the back transformation of the β (Exp(β)) was also determined. In this context, the Exp(β) could be described as the ratio of the GMs and can be interpreted as the percentage increase (or decrease) in exposure associated with the factor (compared with the baseline factor level).

The extent of reduction in the between-depot, between-worker (within-depot), and within-worker variance components was also investigated. For results below the LOD, levels were imputed following a technique described by Lubin *et al.*, (2004). This involved replacing below LOD values with randomly imputed values between zero and the LOD. A single imputation was carried out. All statistical analyses were performed using GenStat software (14th Edition; VSN International Ltd).

RESULTS

Exposure controls walk-through survey

All depots contained one stone cutting workshop which contained the following tools: a water-cooled primary cutting saw and hand tools including disc polisher/cylinder polisher; 5″, 9″, and 12″ angle grinders; pneumatic chisels; hand chisels; brushing tools; and hand punches, as well as a centralized LEV system. The LEV system included one or more movable extraction arms (Nederman Extraction Arm Original) (Nederman, 2010) connected at various locations around the workshop to centralized ducting. The ducting was connected to a Nederman L-PAK 250 compact stationary high-vacuum unit. The inlets used on the extraction arms were plastic with a hood diameter of 16cm. The filtered air was emitted to the external environment through a vent. The water-cooled primary cutting saw was a bridge saw with a 2 m blade. Water was applied to the blade via a recirculating tank at a rate of 100–120 l min^{-1}.

Results of the walk-through survey indicated that there were control measures present in all depots, but they were regularly misused or inadequate for the task. Recommended guidance on engineering controls for stone masonry work involving power tools (HSE, 2006) were not complied with on any of the sites visited. A centralized LEV system was present in all depots, and although there was evidence of correct installation, this system was purchased without consultation with the workers or consideration of the work processes to be controlled. Issues regarding the use of the LEV system observed in all depots included the worker not working within the capture zone of the LEV and the capture arm being unable to deal with the high volumes of dust from tasks such as cutting and grinding.

The LEV systems in place, although working as per specification (capture velocity 11 m s^{-1}, n = 12), were not suitable for the processes that were being carried out in the workshop. The tasks of grinding and cutting stone with a 5″, 9″, and 12″ grinder produced large clouds of dust-laden air too rapidly for it to be captured by the capture arm. Workers regularly worked with large pieces of stone up to 3 m in length, and it was not practical for the worker to regularly reposition the arm as this involved him stopping the task periodically. Capture arms are not recommended for these work tasks for this reason (HSE, 2001, 2011).

RPE was provided in all depots; however, the RPE used by workers varied widely and included nuisance dust masks, positive air purifying respirators, and disposable or reusable negative pressure RPE which in the majority of cases was an FFP3-disposable respirator or half-mask respirator with combination filters. Most RPE had an assigned protection factor of 20. However, there was no evidence of a workplace RPE program comprising of training, fit testing, and a formal purchasing policy for RPE.

Exposure measurements

A total of 103 exposure measurements were collected from 35 stoneworkers. Sampling times ranged from 30–375 min with a median sampling time of 240 min. Repeated measurements were obtained for 19 workers, with the number of repeated measurements for each worker ranging from 2 to 16. Worker tasks measured included cutting stone on a water-cooled primary saw, cutting stone with 5″, 9″, and 12″ angle grinders, grinding stone with 5″ angle grinders, decorating stone with hand and pneumatic chisels, and repointing with a trowel. Stone materials worked on included sandstone, limestone, granite, and lime mortar. RPE was used by workers in 52% of the work tasks sampled. LEV capture hood systems installed were used for all grinding, cutting, and decoration tasks carried out in the stone workshops. Water suppression was used as the primary exposure control on the primary saw.

Figure 1 provides an example of results obtained with the SidePak photometer, which clearly shows the influence of three different tasks carried out by three different workers (grinding sandstone with a 5″ angle grinder in a partially enclosed workshop, cutting sandstone with a 5″ grinder in an enclosed work space, and repointing with lime mortar outdoors) on the dust exposure. During the grinding task, peaks in the dust measurements were due to the worker working outside of the capture zone of the LEV. During the cutting task, between the periods 11.13 and 11.53, the worker was not actively involved in stonework.

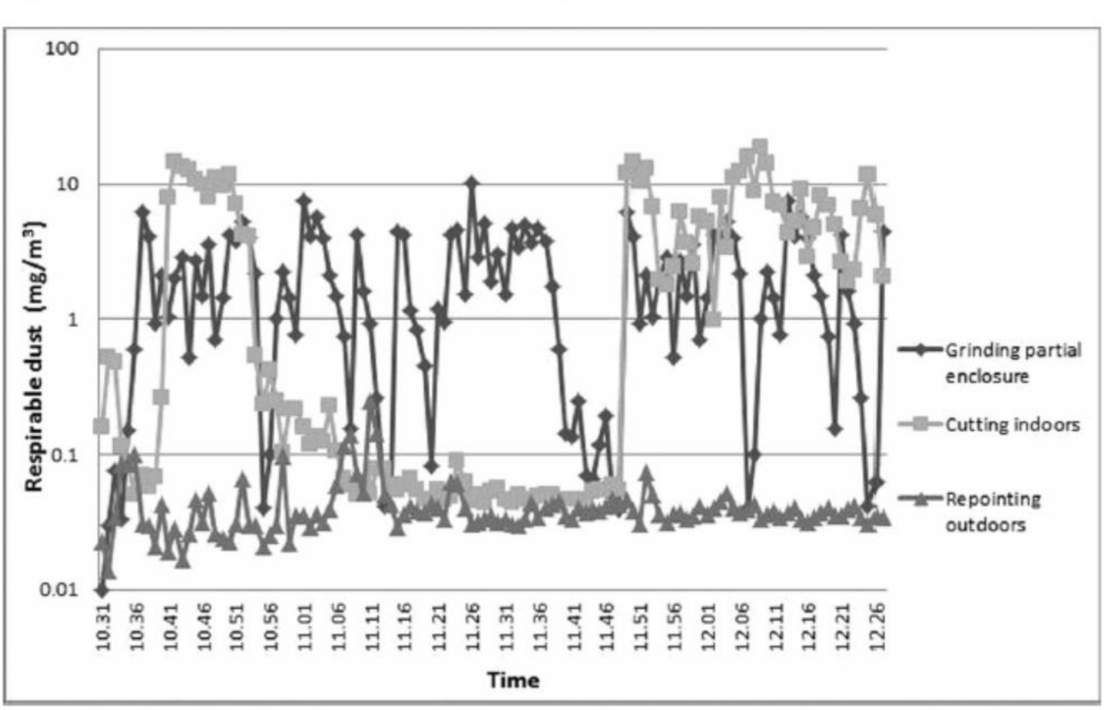

Fig. 1. Photometer results for grinding sandstone with 5″ angle grinder in partial enclosure, cutting sandstone with 5″ angle grinder indoors and repointing with lime mortar outdoors.

Table 2 presents a summary of the personal RCS exposure levels (mg m^{-3}; 8-h TWA) grouped by material worked on and task. All active stonework and related activities carried out during the work shift were sampled and therefore 8-h TWA exposure levels presented are representative of full-shift exposures. RCS exposure for workers working with limestone and repointing with lime mortar (n = 38) ranged from <0.02 to 0.06 mg m^{-3} (8-h TWA). RCS exposure for tasks involving granite ranged from 0.02 to 0.21 mg m^{-3} (8-h TWA); 30% of these measurements exceeded the Irish OELV of 0.1 mg m^{-3}. RCS exposure levels for tasks involving sandstone ranged from <0.02 to 6.00 mg m^{-3} (8-h TWA) with 57% of exposure measurements exceeding the Irish OELV of 0.1 mg m^{-3}. Highest RCS exposure values were recorded for the task of grinding (using a 5″ angle grinder; GM = 0.70 mg m^{-3}) and cutting (using 5″, 9″, and 12″ angle grinders) sandstone (GM = 0.70 mg m^{-3}), respectively (Table 2). Lowest RCS exposure values were recorded for the task of repointing with lime mortar (GM = 0.005 mg m^{-3}). Table 3 presents the percentage of measurements that exceeded the Irish OELV (0.1 mg m^{-3}; HSA, 2011), the occupational exposure standard recommended by the Scientific Committee on Occupational Exposure Limit Values (SCOEL) values (0.05 mg m^{-3}; SCOEL, 2002) and the threshold limit value (TLV) recommended by the American Conference of Governmental Industrial Hygienists (ACGIH; 0.025 mg m^{-3}; ACGIH, 2008).

For tasks involving sandstone, 67 and 76% of RCS exposure levels exceeded the SCOEL recommended OELV of 0.05 mg m^{-3} and the ACGIH TLV of 0.025 mg m^{-3}, respectively. Fifty percent of tasks involving granite exceeded the ACGIH TLV of 0.025 mg m^{-3}, and 7 and 4% of measurements involving limestone and lime mortar, respectively, exceeded 0.025 mg m^{-3} (Table 3 and Fig. 2).

Table 4 shows the coefficients of the fixed effects in the optimal model presented as β, SE, and Exp(β). Due to the natural nesting of workers within depots, three sources of random variance were looked at—between-depot variability, between-workers within-depot, and within-worker variability using mixed effects models (Table 5). After inclusion of the random terms of depot and worker in the model, the fixed effect that was found to be significantly associated with RCS exposure and therefore included in the model was task. Material (granite or sandstone), enclosure, RPE, weather, LEV, and task duration were not found to improve the model so were not included. Table 4

Table 2. Worker personal RCS exposure concentration data (mg m^{-3}; 8-h TWA) grouped by material and worker task.

Material and task	nm	nw	RCS, mg m^{-3}			
			GM[a]	Geometric standard deviation	Range 8-h TWA, mg m^{-3}	Values < LOD
Sandstone	55	14	0.14	10	<0.02[b]–6.00	11
Cutting angle grinder[c]	10	8	0.70	2.2	0.26–1.30	0
Cutting water-cooled primary saw	16	6	0.02	3.9	<0.02–0.13	6
Grinding angle grinder[d]	22	4	0.70	4.5	<0.02–6.00	0
Decoration hand and pneumatic chisel	7	6	0.008	9.0	<0.02–0.07	5
Limestone	15	6	0.008	2.7	<0.02–0.03	13
Cutting angle grinder[c]	1	1	0.01		<0.02	1
Grinding angle grinder[d]	7	3	0.008	1.7	<0.02	7
Decoration hand and pneumatic chisel	7	4	0.007	4.2	<0.02–0.03	5
Lime mortar	23	17	0.005	2.7	<0.02–0.06	22
Repointing	23	17	0.005	2.7	<0.02–0.06	22
Granite	10	3	0.03	4	<0.02–0.21	2
Cutting water-cooled primary saw	4	2	0.01	4.3	<0.02–0.03	1
Grinding angle grinder[d]	6	3	0.06	2.7	<0.02–0.21	1

nm = number of measurements; total = 103, nw = number of workers sampled; total = 35, number of depots = 6.
[a]Samples below the analytical LOD for crystalline silica are reported as <0.02mg.
[b]GM values are computed from the data including the imputed data for the values below LOD.
[c]Grinding carried out with 5″ angle grinder.
[d]Cutting carried out with 5″, 9″ and 12″ angle grinder.

Table 3. Worker personal RCS exposure concentration data (mg m^{-3}; 8-h TWA) grouped by material compared to Irish OELV, SCOEL recommended OELV, and ACGIH TLV for RCS.

Material	% >0.1[a] mg m^{-3}	% >0.05[b] mg m^{-3}	% >0.025[c] mg m^{-3}
Sandstone	57	67	76
Limestone	0	0	7
Lime mortar	0	4	4
Granite	30	40	50

[a]0.1 mg m^{-3} is the Irish OELV.
[b]0.05 mg m^{-3} is the SCOEL recommended OELV.
[c]0.025 mg m^{-3} is the ACGIH TLV.

illustrates that the tasks of grinding and cutting result in average RCS exposures of between 32 and 70 times the exposures recorded for the task of decorating. No estimate was calculated for the task of repointing as this task was not carried out with sandstone or granite. The between-depot, between-worker, and within-worker variance components were reduced by 46, 89 and 49%, respectively, after including task in the mixed effects model (Table 5). The between-worker within-depot variance component was reduced from 0.80 to 0.09, after including task in the model, suggesting that the differences in exposure between workers (within a depot) was predominantly due to differences in tasks between the workers.

DISCUSSION

Exposure concentrations

RCS exposure data for stoneworkers involved in the restoration of historic properties are presented in this article. While exposure to RCS has been well documented in the mining and construction sectors amongst others, there are limited exposure data for stoneworkers involved in restoration stonework and also for stoneworker tasks involving high silica content materials such as sandstone.

Exposure concentrations (<0.02–6 mg m^{-3} RCS 8-h TWA) are within the range of those reported in the literature by HSE (2009; <0.02–7.85 mg m^{-3}

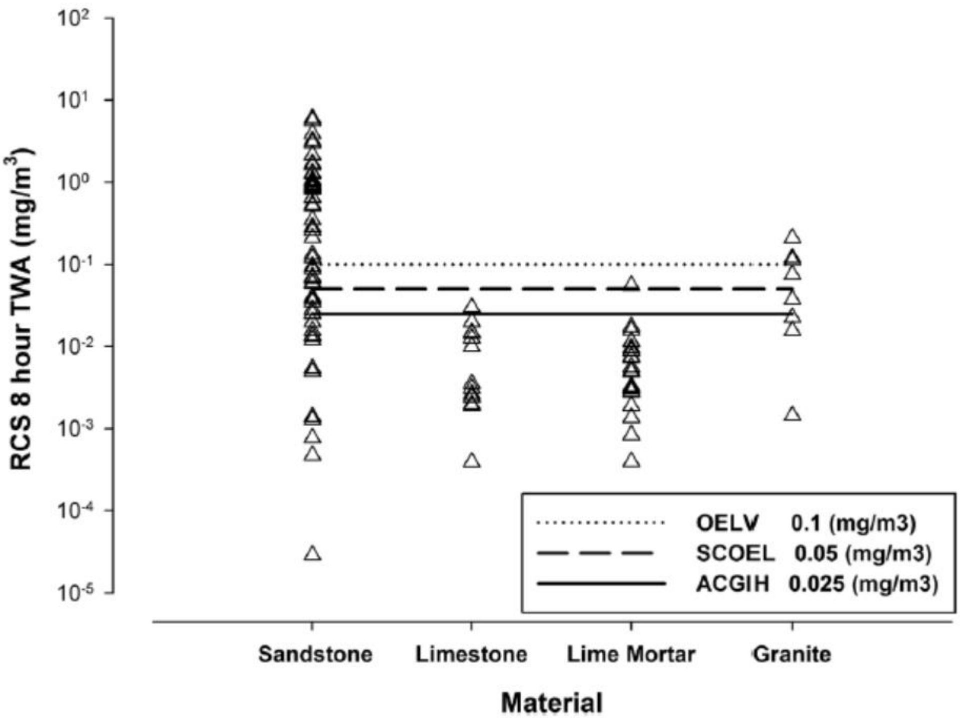

Fig. 2. Worker personal RCS exposure concentration data (mg m^{-3}; 8-h TWA) grouped by material compared with Irish OELV, SCOEL recommended OELV, and ACGIH TLV for RCS.

Table 4. Coefficients for variables affecting exposure to RCS dust in final mixed effects model of the log-transformed exposure to RCS dust among restoration stoneworkers.

	Model 1 (null model)		Model 2 (model 1 + task)		
	β	SE	β	SE	Exp(β)[a]
Intercept	−1.990		−4.46		
Task					
Decorating[b]			0		1
Wet cutting			0.67	0.06	1.95
Grinding			3.48	0.03	32.45
Dry cutting			4.25	0.18	70.10

[a]Exp(β) is the GM ratio and can be interpreted as the percentage increase in exposure associated with the task (compared with the baseline decorating).
[b]The baseline is decorating.

Table 5. Estimated variance components for the random effects and mixed-effects models of the log-transformed exposure to RCS dust among restoration stoneworkers, where below LOD values substituted with imputed values.

	Between-depot variance component	Between-worker within-depot variance component	Within-worker variance component
Model 1 (null model)	1.30	0.80	3.80
Model 2 (model 1 + task)	0.70	0.09	1.92

8-h TWA). Highest concentrations were reported for grinding and cutting of sandstone with 5″, 9″, and 12″ angle grinders, and lowest concentrations were found for repointing with lime mortar and work with limestone. The RCS exposures found in this study are higher than those reported for stoneworkers involved in other sectors, such as construction/roofing (0.04–1.21 mg m^{-3} RCS 8-h TWA), construction/tuck pointing (0.59–2.84 mg m^{-3} 8-h TWA), construction/concrete milling and drilling (0.03–1.3 mg m^{-3} RCS 8-h TWA), demolition workers (0.03–1.3 mg m^{-3} RCS 8-h TWA), and granite top fabrication (0.04–0.77 mg m^{-3} RCS 8-h TWA). The higher concentrations reported in this study are most likely as a result of the high quartz content of the materials used by the workers, i.e. sandstone (33–>82% quartz content) and the large aerosol concentrations created during the tasks involving grinding tools with inadequate engineering controls. It was established that exposure control practices were inadequate for the exposures concentrations found in this study. There was a high reliance on RPE to control exposure; however, the RPE used was not always appropriate, was poorly maintained, and was not face-fit tested. The LEV that was present was not fit for purpose, was often used incorrectly, and was unsuitable for tasks such as grinding and cutting with angle grinders. It was concluded that the current exposure controls in place would not be adequate to reduce exposures to acceptable levels. This was confirmed by the statistical analyses of the data, which showed that the LEV systems currently used in the depots did not reduce exposure significantly. In Ireland, the OELV for RCS is 0.1 mg m^{-3} 8-h TWA (HSA, 2011); a total of 57% of the measurements involving sandstone in this study were well in excess of this value, and 67% were in excess of the OELV recommended by SCOEL of 0.05 mg m^{-3}. Exposure to RCS is associated with a wide range of ill health effects, and the RCS levels reported in this study indicate that members of this occupational group are likely to be at significant risk of overexposure whilst carrying out certain tasks. Although SCOEL recommends an OELV of 0.05 mg m^{-3}, the occupational exposure limit for RCS in Ireland and the UK is 0.1 mg m^{-3}. There is pressure on regulatory agencies to adopt a lower occupational exposure standard; however, progress on this issue has been hindered by issues related to the reliability of the analytical method at lower RCS concentrations (Stacey, 2007). SCOEL has recommended that, to eliminate silicosis, the OELV for RCS should be below 0.05 mg m^{-3}; therefore, the exposure concentrations found in this study have the potential to cause serious health problems among the workers exposed. It is envisaged that the OELV recommended by SCOEL of 0.05 mg m^{-3} will be included in the European Carcinogens Directive or as a binding OELV in the European Chemical Agents Directive once the analytical challenges associated with measuring these low levels of RCS are addressed (Cherrie *et al.*, 2011). The reduction of the OELV and the strict obligations associated with handling a substance listed in the Carcinogens Directive puts greater emphasis on investigating suitable controls for tasks that consistently generate RCS concentrations at levels above the OELV.

Determinants of exposure

Exposure data were used to investigate determinants of RCS exposures in order to identify high-risk tasks for a future workplace intervention study. In the mixed-effects model, task was found to be the only significant ($P < 0.001$) determinant of RCS exposure. Task explained most of the between-worker variance within a depot. This can be explained by the fact that within a depot, certain individuals are responsible for specific tasks as they are trained on the equipment required to carry out the task. Task also reduced the day-to-day and between-depot variance by 49 and 46%, respectively. The reduction in the between-depot variance could be explained by the specialized nature of the work performed at certain depots during the study, for example; due to the availability of a stone cutter, one depot specialized in stone cutting work and another depot focused on repointing a nearby monument. After taking into account the differences in exposure between tasks, the day-to-day or within-worker variance was the largest component followed by the between-depot variance component and the between-worker variance component. Intermittent processes, outdoor work, and mobile work have been described as being associated with increased within-worker variability (Kromhout *et al.*, 1993). The remaining within-worker variance could be related to the fact that the majority of stoneworkers in this study are both mobile and working outdoors whilst located on site. Much of the stonework evaluated in this study would also be intermittent, with periods when the worker would be measuring, marking out, and moving the piece of stone in between active stonework.

CONCLUSION

Findings from this study indicate that restoration stoneworkers grinding and cutting sandstone are regularly overexposed to RCS dust, compared with the Irish OELV of 0.1 mg m^{-3} and SCOEL recommended OELV of 0.05 mg m^{-3} with much lower exposures reported for decorating and wet cutting. Workplace controls, LEV, and RPE provided were not adequate for high-exposure tasks carried out by these workers.

Results from the mixed-effects regression analysis indicates that task is a strong predictor of RCS exposure with the tasks of cutting and grinding sandstone associated with very high levels of RCS exposure. Results also show within-worker variance to be larger than the between-depot variance and between-worker within-depot variance. Hence, any technical interventions should be focused predominantly on grinding and dry cutting tasks and should be appropriate for both workshop and field-based tasks.

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Respirable Crystalline Silica Exposures among Stone Workers in Ireland

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ABSTRACT: Respirable crystalline silica (RCS) concentrations are related to the crystalline silica content of the rock being worked, which means stone workers working with high-silica-content materials can be exposed to excessive levels of respirable dust containing crystalline silica. Little information exists on the RCS exposure concentrations, work practices, and worker knowledge of the hazards associated with RCS exposure among stone workers in Ireland. The objective of this study is to collect information on health and safety practices and worker knowledge of the health risks associated with RCS among stone workers using a questionnaire survey. To design and execute a pilot study to collect personal RCS exposure measurements among a group of restoration stone workers. A self-report quantitative questionnaire was designed based on previously published work and administered to a convenience sample of 130 stone workers engaged in various stonework trades throughout the Republic of Ireland. The questionnaire was designed to collect information on worker demographics, work practices, health and safety practices, knowledge of the risks associated with RCS, and diagnosed respiratory illnesses. Personal exposure measurements of respirable dust were collected using direct reading and gravimetric sampling methods from a group of 14 restoration stone workers working at historic

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sites throughout Ireland. Respirable dust samples were further analysed for RCS. A questionnaire response rate of 48 % ($n = 63$) was achieved. Sixty-six percent of respondents reported regularly using power tools with high-silica-containing materials. The most frequently employed control measure used was respiratory protective equipment (RPE) (85 %), followed by general ventilation (60 %), and more than half of the respondents (58 %) used sweeping as their primary method of cleaning up their work area. Geometric mean 8-h, time-weighted average (TWA) concentrations of RCS ranged from 0.002 to 1.38 mg/m^3, higher concentrations were reported for work involving sandstone, with 78 % of exposure samples exceeding the Irish occupational exposure limit value (OELV) of 0.1 mg/m^3. A training program focusing on inhalation exposure risks associated with RCS and effective engineering controls is needed for this occupational group. The results from this pilot study will be used to design a larger study, involving more exposure measurements, to investigate determinants of RCS exposure within restoration stone masonry. This will aid in the design of a technical intervention for high-risk exposure tasks, involving work with power tools and high-silica-content materials.

KEYWORDS: respirable crystalline silica, stone workers, questionnaire

Introduction

Occupational exposure to RCS has been associated with a range of adverse health effects [1–4]. The most widely reported ill health effect associated with silica exposure is silicosis, an irreversible and progressive disease of the lungs [5–8]. Other health effects are also reported, including cancers [1], autoimmune diseases [9,10], and cardiovascular disease [11].

Workplace exposure to RCS is well documented in many sectors including: construction [12–15], construction/roofing manufacture [16], the heavy clay industry [17], potteries [18], exploration of natural resources (hydraulic fracking) [19], and in stonemasonry [20–22]. However, few studies have focused on RCS exposures of restoration stone workers, especially those carrying out work with high silica content materials [23,24].

When restoring historic buildings, it is often is not possible to substitute high-silica-content materials such as sandstone and granite with low silica content alternatives because of building conservation guidelines. Sandstone and granite were widely used through the centuries in the construction of domestic and public buildings, sculptures, and monuments across Europe. In the United Kingdom, sandstone was used for house building in many of the towns and cities in the north, northeast, and midlands of England, as well as for civic buildings, factories, mills, and engineering projects, such as railway bridges, viaducts, and reservoirs [25]. Local sandstones supplied the majority of buildings constructed in the new and old towns of Edinburgh (now a world heritage site) and the city of Glasgow. In Ireland, sandstone was used in the construction of many pre- and post-Christian monuments, such as passage tombs, high crosses, abbeys, and cathedrals, castles, and monuments, such as the rock of Cashel (a World Heritage Site). Sandstone used in the conservation of Irish monuments, for example, has a crystalline silica content ranging from 50 % to 85 % [26]. RCS levels are related to the crystalline silica content of the rock being worked [27,28], which means stone workers involved in the cutting and grinding of sandstone can be exposed to excessive levels of respirable dust containing crystalline silica. To the author's knowledge, there have been few studies that have characterized the RCS exposures of restoration stone workers [23,24,29]. Also, few have assessed the level of knowledge of the occupational exposure hazards associated with stone working and the use of exposure controls among stone workers [23].

Crystalline silica in the form of quartz and cristobalite is classified as a "Group 1 human lung carcinogen" in the International Agency for Research on Cancer's classification but remains unclassified as a carcinogen under European Union (EU) legislation. Some EU countries have classified RCS as a carcinogen but the National Authority for Occupational Safety and Health in Ireland does not categorize RCS as a human carcinogen in its 2011 Code of Practice for the Chemical Agents regulations. In addition, there is currently no binding OELV for RCS at an EU level and the OELV in Ireland remains at $0.1\ mg/m^3$.

The aim of this research is to design and administer a questionnaire survey to collect information on material and tool usage (work practices), the level of health and safety practice, the level of awareness regarding the hazardous effects of RCS, and the extent of respiratory illness among Irish stone workers. A further aim was to design and execute a pilot study to characterize the RCS exposures of stone workers engaged in the restoration of historic monuments in Ireland. The results from this work will be used to design a larger study to investigate determinants of RCS exposure among restoration stone workers and develop suitable workplace interventions for high-risk exposure tasks.

Methodology

Questionnaire Survey

A self-administered quantitative questionnaire was employed in this study. The objective of the questionnaire is to examine different areas of health and safety practice among Irish stone workers; the questionnaire was designed using previous studies in this area [23] and information gathered during site visits. The questionnaire consisted of five sections including 49 closed questions, 11 open ended questions, and four Likert scale questions designed to acquire information on (1) worker demographics; (2) work and work history (tools, materials, exposure controls used); (3) knowledge of health and safety (safety training and documentation); (4) workplace hazard identification, and (5) health (smoking habits, self- and doctor-diagnosed respiratory illnesses). A pilot of the questionnaire was conducted with four stone workers from the sculptor, monumental, and stone restoration trades. Amendments were made based on the results of the pilot study. A convenience sampling approach was followed. The questionnaire was posted to a sample of 130 stone workers from a population of 423 from various occupations throughout the Republic of Ireland. Stone worker contact details were identified, using national and online directories associated with sculptor and monumental stonework trades excluding construction workers. These directories included the Crafts Council of Ireland and www.build.ie. The questionnaire was posted with an explanatory cover letter to all identified stone workers and reminder phone calls were used to follow up with all non-responders.

Exposure Assessment Methodology

The exposure assessment element of this study was carried out over a 5-month period between November 2009 and March 2010. Workers employed as restoration stonemasons and stonecutters at various historic properties and workshops throughout Ireland were randomly recruited in coordination with the Health and Safety Unit of the Irish Commissioners for Public Works. A short questionnaire was administered to the participants to gather information on tasks, tools, work practices, and stone materials used. The questionnaire was designed using information gathered during preliminary site visits and previous research in this area [13,23]. Based on the information gathered, a list of common tasks was compiled for further evaluation.

Gravimetric Sampling and Analysis

Gravimetric samples were collected using an air sampling pump (Sidekick pump; SKC Ltd., Dorset, United Kingdom) with a Safety in Mines Personal Dust Sampler (SIMPEDS) from Casella, whose design is based on the Higgins-Dewell sampler (part no. 116000B (conductive plastic), Casella, Bedford, United Kingdom) and 25 mm, 5 μm pore size polyvinyl chloride (PVC) filters (GLA 5000; SKC Ltd., Dorset, United Kingdom) pre-calibrated to a flow rate of 2.2 l/min with a primary air flow meter (DryCal DC Lite, model 717-KLS; BIOS International, NJ, United States). The sampling pump was attached to a belt around the waist of the worker or to a harness. The sampler was attached to the worker's lapel within 30 cm of his breathing zone, ensuring the sampler inlet was in a downward vertical position. Sampling periods ranged from 70 to 375 min with a median sampling time of 260 min. Task sampling was performed, and when sampling a work task, all preparatory work, repositioning of stone, and clean-up activities after the task were monitored. Exposure task data was expressed as 8-hr TWA, and it was assumed that the RCS exposure for the remainder of the work shift was zero for the following reasons: the worker was not actively carrying out stonework and was instead carrying out work activities such as driving a forklift or transporting finished stone pieces to the monument. In addition to this, the worker being monitored was working away from the stone workshop or any colleagues carrying out stonework. The mass of respirable dust in the sample was quantified gravimetrically as per Health and Safety Executive (HSE) Methods for the Determination of Hazardous Substances (MDHS) 14/3 [30], and the RCS content on the filter was quantified by X-ray diffraction as per HSE MDHS 101 [31]. The detection limit for quartz and cristobalite by XRD was 0.02 mg.

Photometric Sampling

Photometric data was collected using a TSI SidePak AM510 personal aerosol monitor (TSI Incorporated, Shoreview, MN, United States) adjusted to measure respirable dust using a 10-mm Dorr-Oliver cyclone attachment (part no. 801701, TSI Incorporated, Shoreview, MN, United States) with a TSI standard inlet with no impactor insert (part no. 801702, TSI Inc., Shoreview, MN, United States). The SidePak was calibrated to the recommended flow rate of 1.7 l/min using a primary air flow meter (DryCal DC Lite, model 717-KLS; BIOS International, NJ, United States) and was set to log data at 1-min intervals. The cyclone was attached to the worker's lapel within 30 cm of his breathing zone, ensuring that the cyclone inlet was in a downward vertical position. Sampling times ranged from 70 to 375 min. The photometric data was used to quantify worker exposure patterns while different tasks were carried out, and the data was downloaded for computer analysis using TSI Trackpro software. The SidePak is pre-calibrated by the manufacturer with Arizona road dust (ISO 12103, Al ultrafine test dust), which is the factory default calibration factor of 1. It is recommended that a custom calibration factor be determined to correct for differences between the Arizona road dust and the dust being measured. This was carried out following TSI's application note ITI-099, which involved running the SidePak monitor and gravimetric respirable dust sampler side by side during exposure measurements.

Statistical Analysis

All statistical analyses were performed using GenStat software (14th Ed.) (VSN International Ltd.). The geometric mean (GM) and geometric standard deviation (GSD) of the 8-hr TWA average exposure data were calculated. Responses from the questionnaire survey were analyzed separately for materials using these groupings: sandstone and other materials. Descriptive statistics were used to characterize the demographics, materials and tools used, health, and exposure control usage among the participants.

Results

Questionnaire Survey Results

A response rate of 48 % ($n = 63$) was achieved to the questionnaire survey. It is suspected that the economic recession, which has greatly affected the buildings business trade in Ireland, is partially responsible for the low response rate. Most of the respondents were male (95 %; $n = 60$), between 25 and 64 years old (95 %; $n = 60$). The majority of respondents had been working in the stone trade for 10 to 30 years (71 %; $n = 45$), 12 % having worked < 10 years and 13 % for over 30 years. Among the stone workers included, 45 % were sculptors ($n = 16$) or worked in stone cladding ($n = 12$).

A total of 48 respondents reported that they worked with high silica content stone such as sandstone, flint, and quartzite of which 87 % ($n = 42$) used high-risk tools such as angle grinders and handheld concrete saws. Participants also identified the control measures and clean-up techniques employed by them while using high silica content materials. The most frequently employed control measure was the use of RPE (85 %), followed by general ventilation (60 %) and on-tool water suppression (37 %). Use of local exhaust ventilation (LEV) was low (20 %) with only 11 of the respondents reporting using movable extraction arms ($n = 7$), on-tool ventilation ($n = 2$), or ventilation booths ($n = 1$) (Table 1). More than half of the respondents (58 %) used sweeping as their primary method of cleaning up their work area and almost a quarter of those (24 %) judged cleaning up their work area as a task associated with little or no risk.

The questionnaire survey also investigated the stone worker's knowledge of occupational health and safety and the health risks associated with RCS. Participants in the study were asked to indicate their knowledge of respiratory conditions associated with exposure to silica dust. Of the 63 respondents, 51 % had heard of silicosis only. Almost all of the participants reported to have received health and safety training, but less than half of the respondents indicated that the information had not been covered in enough detail or that their

TABLE 1—*Use of exposure control measures reported by respondents carrying out work with high silica content materials ($n = 48$).*

Control Measures	
RPE	$n = 41$ (85 %)
General ventilation	$n = 29$ (60 %)
On-tool water suppression	$n = 18$ (37 %)
Ventilation/capture arm	$n = 7$ (14 %)
On-tool ventilation	$n = 2$ (4 %)
Ventilation booth	$n = 1$ (2 %)

training did not include aspects of health and safety related to their work with stone. Only two of the survey respondents reported having received information on silica dust hazards or information on exposure controls. In addition to this, less than half of those who had received training had received refresher training (39 %).

Participants were asked to indicate whether they had a company safety policy, workplace risk assessments, and safety procedures in place in their workplace. Only 40 % of the respondents had all three safety documents in place. Only five workers were aware of the current OELV for RCS. The majority of the participants (74 %) reported that they were aware of the National Authority for Occupational Safety and Health in Ireland. A number of guidance documents are published by the HSE in the United Kingdom aimed at helping employers control the risks posed by stonemasonry dust; 69 % of the respondents had not heard of or made use of these documents. Only 36 % of the participants agreed that they were well informed about current health and safety legislation and 46 % knew where to access this information.

Only 35 % of respondents completed the health section of the questionnaire. They were asked to indicate whether or not they had a work-related respiratory illness, whether the illness was self-diagnosed or diagnosed by a doctor, and were allowed to select more than one illness. A response rate of 35 % was achieved for this question and 27 % of these indicated that they did not suffer from any work-related illness. Six respondents reported having work-related respiratory illnesses as diagnosed by a doctor. Asthma was the most reported of these conditions ($n = 4$), followed by sinusitis ($n = 3$), nasal irritation ($n = 2$), and persistent cough ($n = 2$). One respondent reported to have been diagnosed with bronchitis and tonsillitis. 52 % of the survey respondents reported to have smoked, of whom 13 still smoked.

Exposure Assessment Results

Worker tasks measured included cutting stone on a water-cooled primary saw, cutting stone with 5-in., 9-in., and 12-in. angle grinders, grinding stone with 5-in. angle grinders, decorating stone with hand and pneumatic chisels, and repointing with a trowel. Stone materials worked on included sandstone, limestone, and lime mortar. An LEV system was used by the workers for all tasks excluding repointing. This system included one or more extraction arms connected at various locations around the workshop to centralized ducting. The ducting was connected to a Nederman L-PAK 250 compact stationary high vacuum unit.

Table 2 presents the results from the exposure assessment element of this study. 23 personal exposure measurements were taken from 14 workers. A summary of the range of respirable dust and RCS personal exposure data presented as task concentration, RCS 8-hr TWA concentration and geometric

TABLE 2——*Summary of the respirable dust and RCS task concentration (mg/m^3) and RCS worker personal exposure concentration data (mg/m^3) expressed at 8-hr TWA.*

Material	*nm*	*nw*	Respirable Dust Task Concentration Exposure Measurement Range (mg/m^3)	RCS Task Concentration Exposure Measurement Range (mg/m^3)	RCS 8-hr TWA Exposure Measurement Range (mg/m^3)	RCS 8-hr TWA GM	RCS 8-hr TWA GSD
Sandstone	$n = 9$	5	0.70–43.4	<0.1–6.3	0.07–1.7	0.2	4.8
Grinding angle grinder	$n = 4$	2	2.6–43.4	2.3–6.3	1.05–1.7	1.38	1.24
Decoration	$n = 1$	1	1.97	0.2	0.07	–	–
Cutting angle grinder	$n = 2$	2	0.91–2.24	0.47–0.66	0.26–0.53	0.37	1.6
Cutting water-cooled primary saw	$n = 2$	2	0.70–1.92	<0.1–0.2	<0.02–0.12	0.02	3.6
Limestone	$n = 8$	3	0.3–4.63	<0.03–<0.12	<0.02	0.006	3.1
Grinding angle grinder	$n = 3$	1	0.67–2.82	<0.03–<0.12	<0.02	0.002	1
Cutting angle grinder	$n = 1$	1	1.56	<0.06	<0.02	0.01	
Decoration	$n = 4$	2	0.3–4.63	<0.04	<0.02	0.01	2.6
Lime Mortar	$n = 6$	6	0.60–3.37	<0.04	<0.02	0.01	1.3
Repointing	$n = 6$	6	0.60–3.37	<0.04	<0.02	0.01	1.3

Note: *nm*, number of measurements; total, 23; *nw*, number of workers sampled; total, 14.

mean and geometric standard deviation RCS 8-hr TWA concentration grouped by material worked on is presented. RCS exposures for workers working with limestone and repointing with lime mortar ($n = 14$) were all <0.02 mg/m^3 (8-hr TWA). RCS exposure levels for tasks involving sandstone ($n = 9$) ranged from 0.07 mg/m^3 to 1.7 mg/m^3 (8-hr TWA) with 78 % of exposure measurements exceeding the Irish OELV of 0.1 mg/m^3.

Figures 1 and 2 illustrate examples of real-time respirable dust measurements taken with the SidePak photometer. This data was used to look at respirable dust exposure patterns and to identify work tasks and tools that created high levels of dust. Figure 1 shows the influence of a 5-in. angle grinder on dust exposure when grinding limestone in a partially enclosed workshop; peak aerosol concentrations at 9:21, 11:13, 11:55, and 12:51 are observed when the worker moved away from the capture zone (one hood diameter) of a fixed LEV unit installed in the workshop. The face velocity of this LEV was 10.4 m/s. Figure 2 shows the aerosol concentration during a task involving sandstone cutting using a water-cooled primary saw; peak concentrations occurred when the worker moved away from the control panel and closer to the saw to check the cutting line on the stone.

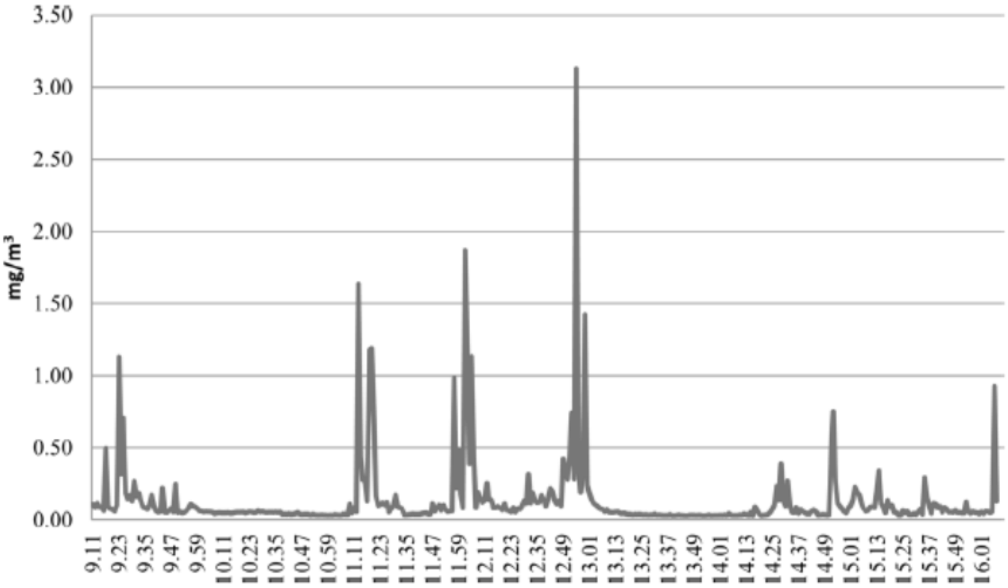

FIG. 1—*Photometer results for worker grinding limestone with a 5-in. angle grinder.*

Photometric and Gravimetric Comparisons

Table 3 presents a summary of the side-by-side gravimetric and photometric measurements ($n = 21$). This data was used to calculate approximate correction factors for three different dust types (sandstone, limestone, and lime mortar). Two sandstone samples were omitted from the analysis because of a very high ratio between the gravimetric and photometric measurements, possibly because of water from the water-cooled saw interfering with the photometer. The average ratio between gravimetric and photometric data for tasks involving

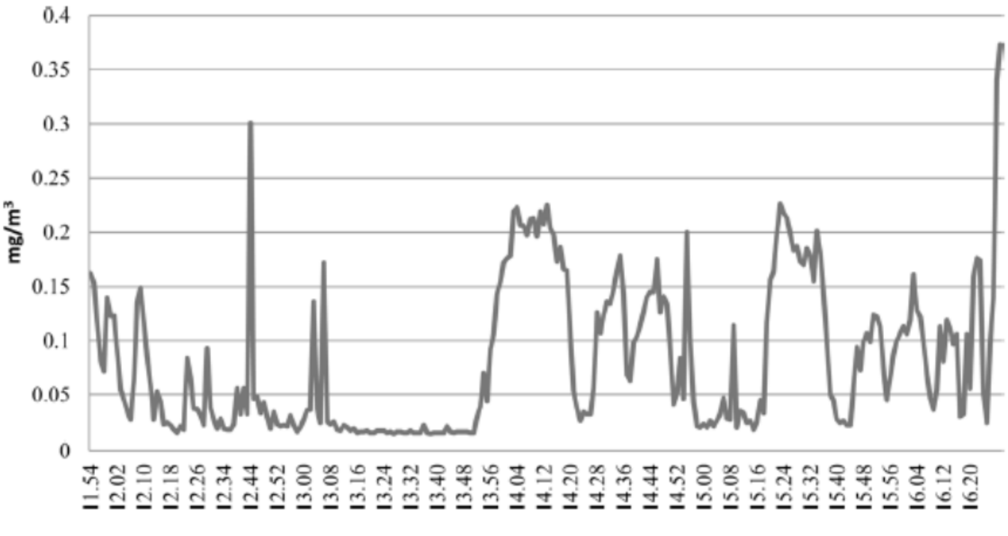

FIG. 2—*Photometer results for worker cutting sandstone with water-cooled primary saw.*

TABLE 3——*Side-by-side average photometric and gravimetric sampling results.*

Material	n	Average Gravimetric Concentration (mg/m^3)	Average Photometric Concentration (mg/m^3)	Approximate Correction Factor	SD
Sandstone	$n=7$	6.8	2.1	3.7	2.5
Limestone	$n=8$	2.6	0.9	3.1	1.1
Lime mortar	$n=6$	0.5	0.3	2.3	1.1

Note: Sampling time range 70–375 min.

limestone and lime mortar was used to calculate approximate calibration factors of 3.1 and 2.3, respectively. A calibration factor of 3.7 was derived for sandstone. The calibration factors reported here are within the range of those reported by [32], in his study of exposure to RCS on an Indian stone (quartz diorite)-crushing site. In this study, a calibration factor of 6.6 was derived for Sidepak measurements where the time history indicated periods >20 mg/m^3 and a calibration factor of 2.4 where the SidePak time history did not exceed this value.

Discussion and Conclusion

Personal RCS exposure measurements were collected from 14 stone workers involved in monumental restoration, using sandstone, limestone, and lime mortar. Highest concentrations of RCS (0.07 mg/m^3–1.7 mg/m^3 8-hr TWA) were found for worker tasks involving sandstone, where 78 % of exposure measurements were greater than the OELV of 0.1 mg/m^3. Lowest concentrations (<0.02 mg/m^3 8-hr TWA) were measured during work with limestone and lime mortar. Exposure concentrations for work involving sandstone and limestone are within the range of those reported in the literature [23] (0.1 mg/m^3–>1 mg/m^3 and <0.1 mg/m^3, respectively). Task exposure concentrations for work with sandstone (<0.1 mg/m^3–6.3 mg/m^3) are comparable to those found in Ref 24 where concentrations for work involving sandstone in the range <0.1 mg/m^3–8 mg/m^3 were reported. The RCS exposures found in this study are higher than those reported for stone workers involved in other sectors, for example, granite top fabrication (<0.04 mg/m^3–0.77 mg/m^3 RCS 8-hr TWA) [33], construction/concrete milling and drilling (0.03 mg/m^3–1.3 mg/m^3 RCS 8-hr TWA) [34], construction/roofing (0.04 mg/m^3–1.21 mg/m^3 RCS 8-hr TWA) [12], and demolition workers (0.03 mg/m^3–1.3 mg/m^3 RCS 8-hr TWA) [35]. Respirable dust task exposure concentrations for work with sandstone and limestone ranged from 0.33 to 43.4 mg/m^3 and 0.55 to 4.63 mg/m^3, respectively.

Photometric data was used to supplement exposure measurements and allowed the identification of high aerosol generating work activities. The high exposure concentrations reported in this study can be attributed to the use of materials with a high quartz content, in combination with the use of power tools such as angle grinders, pneumatic chisels, and unsuitable exposure controls.

During the exposure assessment, the researcher observed the workers use of exposure controls. Recommended guidance on engineering controls for stonemasonry work involving power tools [36] was not complied with on any of the sites visited. There was a high reliance on RPE to control exposure at all sites visited; however, the RPE used was not always appropriate and was poorly managed and maintained at most sites. Similar findings were reported in the questionnaire survey, respondents were largely unaware (69 %) of guidance on engineering controls specific to this sector [37] and relied mainly on RPE for exposure control. In addition, >50 % of these workers used sweeping as their primary method of cleaning up their work area. This indicates a low level of awareness of the hazards associated with RCS exposure among this group, and highlights a need for training inclusive of information on hazards associated with RCS as well as causes of exposure and suitable exposure controls for stonework.

These findings are similar to that in Ref 23 where it was also reported that engineering controls were not present or inadequate in stonemasonry workshops and that there was still a high reliance on RPE to control high exposures.

Only 35 % of survey respondents completed the health section of the questionnaire. None of the respondents indicated that they suffered from a long-term respiratory illness like silicosis, emphysema, or lung cancer. Over the period 2005–2011, eight cases of work-related pneumoconiosis attributed to silica have been reported to the Republic of Ireland, Surveillance of Work-Related and Occupational Respiratory Disease scheme and no cases of silicosis or silica-related pneumoconiosis were reported to the Irish Occupational Physicians Reporting Activity over the period 2007–2010 [38], although it is thought that this is an underestimation of the true number of silica-related respiratory diseases in Ireland [39].

Internationally, the association between occupational exposure to RCS and the development of silicosis has been well reported [6,40,41]. RCS has a steep dose–response relationship, with a reported 2.5 % risk of developing silicosis at average daily exposures of $0.1\,mg/m^3$ RCS (8-hr TWA) over a 15-year period and a 20 % risk at exposure concentrations of $0.3\,mg/m^3$ [42]. Exposure concentrations measured here for work involving power tools and sandstone are well in excess of these values. 76 % of questionnaire respondents reported regularly working with high silica content materials, materials such as sandstone, flint, and quartzite of which nearly 90 % used power tools such as angle grinders and concrete saws. These work practices are likely to generate very high concentrations of RCS dust in the workplace, and suggest that many of these restoration stone workers are potentially at risk of overexposure to RCS dust. This is compounded by poor health and safety practice and a lack of awareness of the health risks associated with stonework and exposure to RCS within this sector and warrants the need for a larger exposure study and workplace technical intervention for high-risk exposure tasks.

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Silica and Associated Respirable Mineral Particles
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Performance of High-Flow-Rate Samplers for Respirable Crystalline Silica Measurement Under Field Conditions: Preliminary Study

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ABSTRACT: Restoration stone work regularly involves work with high-silica-content materials (e.g., sandstone), but low-silica-content materials (<2 % quartz) such as limestone and lime mortar are also used. A combination of short sample duration and low silica content makes the quantification of worker exposure to respirable crystalline silica (RCS) difficult. This problem will be further compounded by the introduction of lower occupational exposure standards for RCS. The objective of this work was to determine whether higher-flow samplers might be an effective tool in characterizing lower RCS concentrations. A short study was performed to evaluate the performance of three high-flow samplers (FSP10, CIP10-R, and GK2.69) using side-by-side sampling with low-flow samplers (SIMPEDS and 10-mm nylon cyclones) for RCS exposure measurement at a restoration stonemasonry field site. A total of 19 side-by-side sample replicates for each high-flow and low-flow sampler pair were collected from work tasks involving limestone and sandstone. RESULTS. Most of the RCS (quartz) masses collected with the high-flow-rate samplers were above the limit of detection (62 % to 84 %) relative to the low-flow-rate samplers (58 % to 78 %).

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The average of the respirable mass concentration ratios for CIP10-R/SIMPEDS, GK2.69/10-mm nylon, FSP10/SIMPEDS, and FSP10/10-mm nylon pairs and the range of the quartz concentration ratios for the CIP10-R/SIMPEDS, CIP10-R/10-mm nylon, GK2.69/10-mm nylon, FSP10/SIMPEDS, and FSP10/10-mm nylon pairs included unity with an average close to unity, indicating no likely difference between the reported values for each sampler. Workers reported problems related to the weight of the sampling pumps for the high-flow-rate samplers. Respirable mass concentration data suggest that the high-flow-rate samplers evaluated would be appropriate for sampling respirable dust concentrations during restoration stone work. Results from the comparison of average quartz concentration ratios between high- and low-flow samplers suggest that the higher mass collected by the high-flow-rate samplers did not interfere with the quartz measurement. A significant portion of the data collected with the high-flow-rate samplers ($>$82 %) were greater than the limit of detection, which indicates that these samplers are suitable for quantifying exposures, even with low-quartz materials.

KEYWORDS: Respirable crystalline silica, Occupational exposure assessment, Stone masonry

Introduction

Silicosis is one of the oldest, often fatal, occupational diseases and is caused by inhalation of respirable crystalline silica (RCS). Silica is an abundant mineral in Earth's crust, and exposures are documented for workers involved in construction, mining, quarrying, and related industries [1–5]. Despite improvements in work practices and exposure controls, occupational exposure to RCS still remains a challenge for the occupational health and hygiene professional; it is estimated that approximately 5.3×10^6 workers in Europe [6] and approximately 1.7×10^6 workers in the United States [7] are exposed to RCS today.

RCS is classified as a Group 1 carcinogen by the International Agency for Research on Cancer [8]. In Europe, the EU Commission Scientific Committee on Occupational Exposure Limits [9] recommended that a European occupational exposure standard of 0.05 mg/m^3 be implemented to reduce the risk of silicosis. However, in many European countries, including Ireland and the United Kingdom, the occupational exposure limit for RCS is 0.1 mg/m^3. The UK Health and Safety Executive, in their evaluation of scientific evidence on the hazardous effects of RCS [10], described the risk of developing silicosis after 15 years of exposure at 0.1 mg/m^3 as 2.5 %, and there is increasing pressure on regulatory agencies to implement a decreased exposure standard to reduce the risk of silicosis.

An issue with enforcing an exposure limit of less than 0.1 mg/m^3 relates to the sensitivity of the current analytical techniques, x-ray diffraction (XRD) [11,12], and infrared analysis (IR) [13]. As explained by Stacey in 2007 [14], the theoretical limit of detection (LOD) of the analytical techniques (5 to 10 μg per sample, equivalent to 0.005 to 0.01 mg/m^3 for an 8-h sample collected at 2.2 l/min) is difficult to achieve in real samples because of issues such as sampling times less than 8 h, measurement precision, interferences in the sample, and reliable calibration standards. Using respirable aerosol sample collectors operating at 1.7 to 2.2 l/min, it will therefore be difficult to demonstrate compliance with a reduced occupational exposure limit (OEL) of less than 0.1 mg/m^3, especially when measuring work tasks lasting less than 8 h. One option available to increase the sample mass collected for RCS analysis is to use high-flow-rate samplers. Commercially available high-flow-rate samplers include the CIP10-R [15], the GK2.69 cyclone [16], and the FSP10 cyclone [17]. The feasibility of using these high-flow samplers to increase the sample mass collected and improve the reliability of RCS measurement at low RCS concentrations has been evaluated in laboratory studies [18–20].

Lee et al. [19] showed that the high-flow-rate samplers collected 2 to 11 times more dust (based on gravimetric analysis) than low-flow-rate samplers (10-mm nylon and Higgins-Dewell-type cyclones). The samplers overestimated exposure to respirable particles relative to the ISO/CEN/ACGIH respirable convention curve; however, two of the samplers evaluated, the GK2.69 and FSP10 cyclones, provided relatively less biased estimates of RCS when flow rates were adjusted to 4.4 and 11.2 l/min, respectively. Stacey and Thorpe [18] similarly recommend the use of high-flow-rate samplers, specifically, the FSP10 cyclone (GSA Messgerätebau GmbH) and the GK2.69, but results from their field trials suggest that further work is needed to address pump flow-rate performance. A further issue that needs to be addressed is worker discomfort due to pump weight.

The increased mass collected by high-flow-rate samplers also improved the reliability of analytical measurements of RCS by Fourier transform IR and XRD, especially for environments with low silica concentrations [20]. However, Stacey [14] cautions that high-flow-rate samplers might not be appropriate for dusty environments with low silica concentrations, as large filter loadings might cause absorption effects with XRD analysis and be unsuitable for direct on-filter IR.

Few studies [18] have evaluated the use of high-flow-rate samplers in real occupational environments. Such studies are required in order to assess the samplers' practical use in the field and to validate results from laboratory studies. Restoration stonemasons regularly work with low-silica-content materials such as limestone and lime mortar. Because of the duration of the work tasks involving such materials—for example, repointing a limestone building—it is often not possible to quantify RCS exposures using traditional sampling techniques with sample collectors operating between 1.7 and 2.2 l/min. The objective of this study was to evaluate three high-flow-rate samplers (CIP10-R, GK2.69, and FSP10) for RCS exposure measurement at a restoration stonemasonry field site during work activities involving limestone and sandstone.

Materials and Methodology

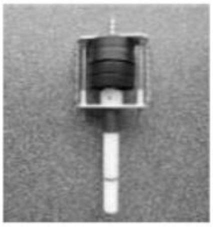
Low-Flow-Rate Samplers

The low-flow-rate samplers included in this study were (i) the Safety in Mines Personal Dust Sampler (SIMPEDS) (Model 116000B plastic cyclone, Casella, Bedford, UK) with 25-mm 5-μm pore size polyvinyl chloride (PVC) filters (GLA 5000; SKC Ltd, Dorset, UK) sampling at a flow rate of 2.2 l/min with a Sidekick pump (SKC Ltd) and (ii) the 10-mm nylon cyclone (Sensidyne, Clearwater, FL) with 37-mm 5-μm pore size PVC filters (GLA 5000; SKC Ltd) sampling at a flow rate of 1.7 l/min with a Sidekick pump (SKC Ltd) (Table 1).

High-Flow-Rate Samplers

The high-flow-rate samplers included in this study were (i) CIP10-R (Arelco ARC, Paris, France) with polyurethane foam in a rotating cup sampling at a

TABLE 1—*Comparison of high- and low-flow-rate samplers employed in this study.*

Sampler		Flow Rate, l/min	Sampling Media	Pump
10-mm nylon cyclone (Sensidyne, USA)		1.7	PVC filter (37 mm, 5-μm pore size)	Sidekick
SIMPEDS cyclone (Casella, UK)		2.2	PVC filter (25 mm, 5-μm pore size)	Sidekick
CIP10-R (Arelco ARC, France)		10	Polyurethane foam	—
GK2.69 (BGI Inc., USA)		4.4	PVC filter (37 mm, 5-μm pore size)	SKC Legacy
FSP10 (BIA, Germany)		11.2	PVC filter (37 mm, 5-μm pore size)	SG10-2

flow rate of 10 l/min, (ii) GK2.69 (BGI Inc., Waltham, MA) with 37-mm 5-μm pore size PVC filters (GLA 5000; SKC Ltd) sampling at a flow rate of 4.4 l/min with an SKC Legacy pump (SKC Inc., Eighty Four, PA), and (iii) FSP10 GSM (Gesellschaft für Schadstoffmesstechnik GmbH, Neuss, Germany) with 37-mm 5-μm pore size PVC filters (GLA 5000; SKC Ltd, Dorset, UK) sampling at a flow rate of 11.2 l/min with an SG10-2 pump (GSM GmbH) (Table 1).

Sample Preparation

Field Site Description—Field data were collected at five stonemasonry field sites. Four of the sites were restoration stonemasonry workshops managed by the Commissioners for Public Works in Ireland, who are responsible for the restoration and maintenance of historic properties in Ireland. The work sites were chosen because the National University of Ireland, Galway is engaged in an ongoing project [21] to evaluate RCS exposures of restoration stonemasons working at these sites. Within each of the workshops, stone workers were employed as either stone cutters or stonemasons, and each workshop contained the following stonemasonry tools: water-cooled primary cutting saw and hand tools including a disc polisher/cylinder polisher; 5-in., 9-in., and 12-in. angle grinders; pneumatic chisels; hand chisels; brushing tools; and hand punches. At the time of the study, workers were working with either sandstone or limestone. One additional field site, operated by a self-employed stonemason working with sandstone paving, was also included in the study.

Sample Preparation

Prior to sampling, filters and foams were preconditioned in a temperature- and humidity-controlled laboratory at the School of Physics, National University of Ireland, Galway (NUIG) for 24 h. Pre-weighing was performed in this laboratory. Before weighing, filters and foams were passed under a static eliminator (Sartorius, YIB01-OUR ionizing blower, Sartorius, Göttingen, Germany). Pre-weighing of PVC filters and of PVC filters and cassettes (SIMPEDS) was performed using a Sartorius M55-F Microbalance (Sartorius, Göttingen, Germany). Rotating cups with foam of CIP10-R were pre-weighed using an analytical balance (Mettler AE240, Mettler, Toledo, OH). Pre-weighed filters (37-mm PVC filters) were placed into filter holders, sealed, and labeled to prevent contamination. In the field, all pumps were precalibrated using a primary air flow meter (DryCal DC Lite, model 717-KLS, BIOS International, NJ). The flow rate of the CIP10-R was initially calibrated to 10 l/min with a CIP10 calibration bench (Arelco, ARC) in the laboratory, and the rotational speed of the cup was checked using a tachometer in the field.

Sample Collection

Contextual information was recorded during the measurement period, including details about the task, tools, and materials and worker feedback on the sampling equipment.

Side-by-side sampling with six combinations of high- and low-flow-rate samplers was performed. Because of the limited number of workers, personal sampling was conducted only for the FSP10–10-mm nylon cyclone pair and the FSP10–SIMPEDS cyclone pair. Other pairs of high- and low-flow-rate samplers were placed as near to the worker as physically possible by placing the samplers at 1.5 m using a tripod. Tripods were positioned approximately 0.5 to 1.5 m from the worker. A total of 19 pairs for each combination of samplers were collected. Sample duration depended on visual estimation of apparent respirable dust mass concentration and varied from 10 to 60 min (median: 30 min). In some cases it was decided not to continue sampling for the full work task, to avoid overloading the high-flow sampler filters.

Sample Analysis

All sampling trains were post-calibrated; PVC filters, polyurethane foams, and cassettes with PVC filters were returned to the laboratory at NUIG and pre-conditioned and post-weighed, and dust concentrations were calculated. Samples were hand-carried to the National Institute for Occupational Safety and Health (NIOSH) (Morgantown, WV) for analytical analysis at their contract laboratory following NIOSH Method 7500 (NMAM, 4th ed.) [12]. Each filter was removed from the plastic sample holder and transferred to a 15-ml vial. Care was taken to include all particulate matter. If any visible particulate remained in the holder, it was wiped and included for analysis. Then, approximately 10 ml of tetrahydrofuran (THF) was added to each sample vial. The samples were mixed by vortex and then placed in an ultrasonic bath for 10 min. Each sample suspension was transferred to a silver-membrane filter. First, a silver-membrane filter was placed in the vacuum filtration unit. Then, 2 ml of THF solvent was placed onto the filter. The sample suspension was vortexed and immediately added onto the silver membrane filter. The sample vial was rinsed with three separate 2-ml portions of THF. Each rinse was added to the sample on top of the silver-membrane filter. Finally, vacuum was applied to deposit the suspension onto the filter. The silver-membrane filter was then transferred to an aluminum sample plate and placed in the automated sample changer for analysis via XRD. Quartz was the only polymorph of RCS determined to be present. The LOD for quartz was 6 μg. Prior to analysis, dusts from the CIP10-R polyurethane foams were extracted by adding isopropyl alcohol to the foam in its rotating cup, which was then placed in an ultrasonic bath for 5 min, filtered onto a 37-mm PVC filter, rinsed with isopropyl alcohol, and allowed to dry.

Data Analysis

Net mass and mass concentration ratios (respirable dust and quartz) were calculated and compared by dividing the net mass or mass concentration from the high-flow sampler by the net mass or mass concentration from the paired low sampler. Outliers, defined as ratios of less than 0.3 and greater than 3.0, and data below the LOD were removed from the data set. Twenty-three quartz samples collected from the SIMPEDS combinations were removed because their values were less than the LOD; all these samples were collected on tasks involving limestone. Thirty-eight quartz samples collected from the 10-mm nylon sampler combinations were removed because their values were less than the LOD. There were 161 valid quartz samples. There were 225 valid respirable dust samples. However, because of environmental variables that are not controlled in the field, unlike in the laboratory, the number of samples required to show a difference between samplers can be very large. For inhalable samples, Lee et al. [22] estimated that a minimum of 30 pairs was required to prove a difference greater than 35 % (or similarity within 35 %) at a *p*-value of 0.05 and a confidence level of 80 %. It is possible that smaller numbers may be required to prove similar differences in respirable dust samples, but it is still likely that the number of samples needs to be more than just a few. Thus only those comparisons in which the number of valid pairs is reasonably large (for example, greater than 11) should be considered as indicating a likely difference between samplers.

Results

Contextual Information

Samples were collected on different dates and on real work activities, and so the number of sample replicates for the various sample heads and materials differs between Tables 2 and 3. Work sampled using the 10-mm nylon sampler combinations involved McMonagles sandstone (60 % quartz), and work sampled using the SIMPEDS combinations involved Killarney sandstone (33 % to 52 % quartz) [23]. In many cases the sandstone was damp before use, as it was stored outside, and in some cases (9 of the 19 SIMPEDS trials) the sandstone was pre-soaked by the workers before use. All of the SIMPEDS trials except one (performed outdoors) were carried out in a partially enclosed environment (similar to that shown in Fig. 1). Seven out of the 19 trials involving the 10-mm nylon cyclone were conducted outdoors; the remainder were carried out in a partially enclosed environment similar to that in Fig. 1. Exposure controls used by the workers varied; some wore respiratory protective equipment such as positive air purifying respirators or disposable respirators, and local exhaust ventilation in the form of a movable extraction arm

TABLE 2—*Summary of average respirable dust concentrations and respirable crystalline silica concentrations collected using CIP-10R, FSP-10, GK2.69, and SIMPEDS cyclone.*

Sampler	Task	Material	Number of Samples	Sampling Time, min	Average Respirable Dust Mass Concentration, mg/m^3	Average RCS Mass Concentration, mg/m^3
CIP-10R	Cutting and grinding	SS	14	10 to 40	27	15.7
CIP-10R	Grinding	LS	4	30	5.8	0.24
GK2.69	Cutting and grinding	SS	15	10 to 40	5	3.3
GK2.69	Grinding	LS	4	30	1	<LOD
FSP10	Cutting and grinding	SS	14	10 to 40	34.2	25.0
FSP10	Grinding	LS	4	30	8.3	0.21
SIMPEDS	Cutting and grinding	SS	43	10 to 40	40	27.0
SIMPEDS	Grinding	LS	11	30	8	0.47

Notes: SS, sandstone; LS, limestone; <LOD, less than the limit of detection.

(Nederman Extraction Arm Original) connected to a Nederman L-PAK 250 compact stationary high-vacuum unit was used when available (7 of the SIMPEDS trials and 11 of the 10-mm nylon trials).

Exposure Concentrations

Average respirable mass concentrations and RCS concentrations collected with high-flow-rate and SIMPEDS cyclones are presented in Table 2, and

TABLE 3—*Summary of average respirable dust concentrations and respirable crystalline silica concentrations collected using CIP-10R, FSP-10, GK2.69, and 10-mm nylon cyclone.*

Sampler	Task	Material	Number of Samples	Sampling Time, min	Average Respirable Dust Mass Concentration, mg/m^3	Average RCS Mass Concentration, mg/m^3
CIP-10R	Cutting	SS	11	15	32	7.0
CIP-10R	Grinding	LS	8	60	2	0.07
GK2.69	Cutting	SS	11	15	20.8	8.6
GK2.69	Grinding	LS	8	60	1.4	<LOD
FSP10	Cutting	SS	11	15	43.7	12.7
FSP10	Grinding	LS	8	60	6	0.04
10-mm nylon	Cutting	SS	33	15	14.5	5.0
10-mm nylon	Grinding	LS	24	60	1.4	<LOD

Notes: SS, sandstone; LS, limestone; <LOD, less than the limit of detection.

FIG. 1—*Restoration stonemason wearing the FSP-10 paired with the SIMPEDS cyclone, close by on the tripod, CIP10-R/SIMPEDS and GK2.69/SIMPEDS sampler combinations.*

average respirable mass concentrations and RCS concentrations collected with high-flow-rate and 10-mm nylon cyclones are presented in Table 3. A number of samples were removed because of field or laboratory errors (five samples from Table 2). In general, high concentrations of both respirable dust (5 to 43.7 mg/m^3) and RCS (3.3 to 27 mg/m^3) were collected for all tasks involving sandstone, and lower concentrations of respirable dust (1 to 8.3 mg/m^3) and RCS (<LOD to 0.47 mg/m^3) were collected for tasks involving limestone.

The proportion of RCS sampled in the respirable dust was greater with the SIMPEDS combinations than with the 10-mm nylon combinations, and there was more variability in the proportion of RCS in respirable dust in the 10-mm nylon trials (0.2 to 0.4, compared with 0.6 to 0.7 for SIMPEDS). Sample data are not compared to the OEL because in some cases, as a result of overloading of the high-flow sampler filters, sampling was stopped before the end of the work task. Previous studies [21] show that exposures to RCS when grinding or cutting sandstone regularly exceed the OEL.

Respirable Dust Mass Concentration and Net Mass Comparison

Average and standard deviations of the respirable mass concentration and net mass ratios of the FSP10, CIP10-R, and GK6.29 to the 10-mm nylon and SIMPEDS cyclones are shown in Table 4.

TABLE 4—*Respirable dust mass concentration ratio and respirable dust net mass ratio of high-flow samplers to 10-mm nylon and SIMPEDS cyclones.*

	Reference Cyclone	CIP10-R	GK2.69	FSP10
Mass concentration ratio	10-mm nylon	2.0 ± 0.54 (n = 5)	1.4 ± 0.7 (n = 16)	1.4 ± 0.73 (n = 6)
	SIMPEDS	0.8 ± 0.3 (n = 17)	0.4 ± 0.2 (n = 4)	11 ± 0.8 (n = 13)
Net mass ratio	10-mm nylon	12 ± 3 (n = 5)	3.5 ± 2 (n = 16)	11 ± 7 (n = 6)
	SIMPEDS	3.7 ± 1 (n = 17)	0.7 ± 0.3 (n = 4)	5.3 ± 4 (n = 13)

Quartz Mass Concentration and Net Mass Comparison

Average and standard deviations of the quartz mass concentration ratios and net mass ratios of the FSP10, CIP10-R, and GK6.29 to the 10-mm nylon and SIMPEDS cyclones are shown in Table 5. None of the quartz mass concentration ratio data collected for the GK2.69 comparison to the SIMPEDS could be used because the values were less than the LOD ($n = 6$) or were outliers (<0.3 [$n = 12$] or >3.0 [$n = 1$]) and so were not included in data analysis.

A scatter plot of quartz mass (micrograms) collected with high- and low-flow-rate samplers with reference lines of LOD (6 μg) and LOQ (limit of quantification) (20 μg) is shown in Fig. 2. Most of the masses collected with the high-flow samplers were above the LOD (CIP10-R, 86 % [$n = 37$]; FSP10, 84 % [$n = 38$]) as compared with the low-flow samplers (SIMPEDS, 78 % [$n = 55$]; 10-mm nylon, 58 % [$n = 57$]). Sixty-two percent of masses collected with the GK2.69 ($n = 38$) were above the LOD. Values below the LOD are not indicated in Fig. 2.

Practical Experience

During the field study, the researcher made some notes regarding the practical use of the sampling equipment. Most of the negative feedback was related to the FSP10 and GSA SG10-2 pumps. There was no attachment on the FSP10 to attach the sampler to the worker, and workers complained that the FSP10 was very heavy and bulky. The GSA SG10-2 pump was difficult to attach to and remove from the sampling harness, and the outlet was in a poor location, which meant that it frequently got blocked during sampling. The workers complained

TABLE 5—*Quartz mass concentration ratio and quartz net mass ratio of high-flow samplers to 10-mm nylon and SIMPEDS cyclones.*

	Reference Cyclone	CIP10-R	GK2.69	FSP10
Mass concentration ratio	10-mm nylon	1.15 ± 0.7 (n = 6)	1.7 ± 0.7 (n = 9)	1.24 ± 0.6 (n = 6)
	SIMPEDS	1.1 ± 0.3 (n = 13)	No data	1 ± 0.8 (n = 4)
Net mass ratio	10-mm nylon	7 ± 4 (n = 6)	1.6 ± 0.7 (n = 9)	8 ± 4 (n = 4)
	SIMPEDS	4.5 ± 2 (n = 13)	No data	5 ± 2.3 (n = 4)

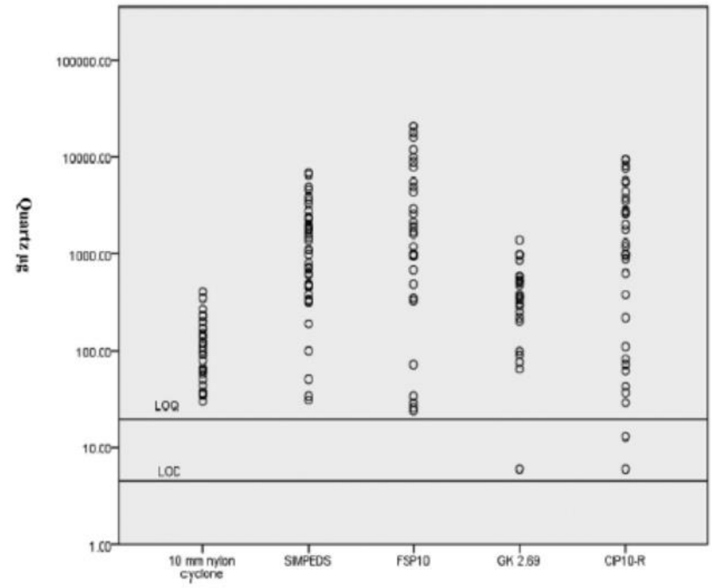


FIG. 2—*Scatter plot of quartz masses collected with the CIP10-R, GK2.69, FSP10, SIMPEDS cyclone, and 10-mm nylon cyclone samplers, showing an LOQ of 20 µg and an LOD of 6 µg from NMAM 7500.*

that the GSA SG10-2 pump was very noisy, and that the Legacy pump was very heavy.

Discussion and Conclusion

The performances of three high-flow-rate samplers in collecting respirable crystalline silica (RCS) (quartz) samples in an occupational setting were evaluated in this study. Although this study was affected by low sample numbers and high standard deviations, some trends are evident in the data.

The ratios of RCS to respirable dust in samples collected in the SIMPEDS sample pairs were higher than the corresponding ratios for the 10-mm nylon pairs (Table 2 compared to Table 3). Furthermore, there was more variability in the ratios calculated for the 10-mm nylon sample combinations. This variation is likely a result of a number of factors, although determining the relative contributions from those factors would require further study. It is likely that there is greater analytical variation in the lower absolute mass of RCS on filters collected in the 10-mm nylon combinations. There was also likely an effect of wind velocity on outdoor sampling, as evidenced by the slightly higher ratios for the GK2.69 sampler, which has a downward-pointing inlet. Finally, the difference in quartz concentrations of the sandstone used in the two trials (33 % to 52 % quartz in the SIMPEDS studies; 60 % in the 10-mm nylon studies) likely reflects a difference in the grain size of the quartz. Airborne sandstone particles are formed from breaking the cement binding the quartz grains together, and it might be that the sandstone with a greater quartz content had larger grains, thus producing airborne particles that were perhaps larger than could be sampled in the respirable fraction.

For those sampler pairs with more than 11 valid pairs, the average of the respirable mass concentration ratios between the CIP10-R and SIMPEDS, the GK2.69 and 10-mm nylon cyclone, the FSP10 and 10-mm nylon, and the FSP10 and SIMPEDS were close to unity (the range of results includes 1.0), suggesting that these samplers would be appropriate for sampling respirable dust concentrations during restoration stone work activities. For the other combinations, in which the number of valid pairs was less than 11, the results likely were affected by the small sample numbers.

Only two sampler pair combinations had more than 11 measurements for quartz concentration ratios, but the mass concentration ratios for all combinations that had data (CIP10-R and SIMPEDS and 10-mm nylon; the GK2.69 and 10-mm nylon and the FSP10 and 10-mm nylon and SIMPEDS) were close to unity (range includes 1.0). This suggests that the greater quartz mass collected by the high-flow-rate samplers did not interfere with the quartz measurements. Eighty-six percent and 84 % of quartz masses collected with the CIP10-R and FSP10 were above the LOD of the analytical method, compared with 78 % and 58 % of the quartz masses collected with the SIMPEDS and 10-mm nylon. Many of the samples greater than the LOD related to work tasks involving limestone, which indicates that the high-flow samplers would be appropriate for sampling RCS concentrations in work activities involving low-silica-content (<2 %) materials. The experience here, where large numbers of the traditional low-flow-rate samplers yielded quartz mass results below the LOD or between the LOD and the LOQ, points to a challenge for planning future comparisons of high-flow-rate and low-flow-rate samplers in the field.

Finally, anecdotal evidence based on discussions with the workers during the field study suggests that sampling pumps such as the GSA SG10-2 pump are not comfortable to wear and could interfere with work activities. Solutions to address pump weight and increase worker comfort during sampling need to be sought.

Acknowledgments

Many thanks to the stone workers of the Irish Commissioners for Public Works for participating this in this survey. Also thank you to Mr. Padraic McGowan, Health and Safety Unit, Irish Commissioners for Public Works, for allowing researchers access to field sites. Funding for this project was received from the National Institute for Occupational Safety and Health (Contract No. 200-2011-M-38869).

Appendix B: Contextual information sheet

Site detail							
Site Name		Date		Workshop/Workspace			
Worker Name & Years Experience		Position		Sampled substance & Sample no		Personal/ Static	

Work Activity/Process					
Activity/Process				Tool/Equipment Power/Hand	

<table>
<tr><td colspan="2">Details of Tool(s)</td><td colspan="7"></td></tr>
<tr><td colspan="2">Description activity/process</td><td colspan="7"></td></tr>
<tr><td colspan="9">Work Area/Controls</td></tr>
<tr><td>Indoor/Outdoor/Partial enclosure</td><td></td><td>Natural ventilation</td><td></td><td>Segregation?</td><td></td><td colspan="2">No of workers in area</td><td></td></tr>
<tr><td>Wet/Dry Work</td><td></td><td>Weather</td><td colspan="3"></td><td>Sources of Secondary dust</td><td colspan="2"></td></tr>
</table>

Work Area/Controls			
Area Room		**LEV Capture velocity/ Effectiveness**	
LEV Type/Details			
PPE		**PPE Details**	

Appendix C: Questionnaire to examine different areas of health and safety practice amongst Irish stoneworkers

May 2011

Dear ___________________________,

I am a research student studying Occupational Hygiene at NUI, Galway.

I would like to invite you to participate in my project which is investigating occupational exposures to silica dust in stonemasonry. I have decided to carry out this research as there is a limited amount of research conducted on this topic in Ireland.

Through your participation, I wish to gather information on the number of workers working with stone in Ireland, types of stone and tools used by these workers and their level of health and safety knowledge. Completion of this questionnaire will assist in identifying the extent to which stonemasons are potentially exposed to silica dust in Ireland.

I would greatly appreciate if you would complete the questionnaire enclosed. It should take about 20 minutes to complete. Most questions are designed to be answered using a tick in a box or rate on a scale of 1-5.

Please be assured that all information you provide is anonymous and will be kept strictly confidential. Once completed, please return the questionnaire in the enclosed postage-paid envelope by **27th May 2011**.

Should you have any questions, please contact me via email at **c.healy5@nuigalway.ie** or by telephone (091) 493403.

Thank you very much for your time and help with this survey.

The purpose of this questionnaire is to gather information for research carried out by the National University of Ireland, Galway, in the area of personal exposure to silica. All information received will remain confidential.

Section 1 – About You

1. How old are you? __________Years

2. Gender: Male Female

3. Highest level of education you have received?

Junior Certificate	Leaving Certificate
Certificate	Diploma
Degree	Higher Diploma
Masters	PhD

4. What percentage of your year is spent working with stone?

25%	50%
75%	100%

5. What percentage of your week is spent working with stone?

25%	50%
75%	100%

6. How many years have you worked with stone? __________Years

SECTION 2 - Your Work & Work History

7. Which group best describes your role in stonework? <u>Please tick only one</u>

Stonecutter	Banker Stonemason
Monumental Stonemason	Restoration / Conservation Stonemason
Construction Worker	Specialising in other stonemasonry work
Fireplaces	Countertops
House fronts / Cladding	Paving / Tiles / Slates
Furniture	Stone carver
Sculptor	Other
Teacher/Instructor	

If other, please specify ____

8. Do you work with any other materials besides stone? e.g. bronze, wood, glass

If yes, please specify ____

9. How many individuals <u>not including family members</u> are employed in the company you work in?

_______________Individuals

10. How many <u>family members</u> are employed in the company you work in?

_______________Family members

11. Do you take on additional help from other stoneworkers during busy periods?

Yes No

12. On average, how many hours per day do you spend working with stone indoors or in a partial enclosure?

Less than 1 hour	1 – 2 hours
3 – 4 hours	5 – 6 hours
7 – 8 hours	9 – 10 hours
11 – 12 hours	More than 12 hours

13. On average, how many hours per day do you spend working outdoors with stone? e.g. away from enclosed structures.

Less than 1 hour	1 – 2 hours
3 – 4 hours	5 – 6 hours
7 – 8 hours	9 – 10 hours
11 – 12 hours	More than 12 hours

14. Do you work with the following types of stone? Select all that apply (If not, please move to question 23)

	Yes	**No**
Sandstone		
Flint		
Quartzite		
Chert		
Siltstone		
Gritstone		
Sand		

15. If you answered no, do you avoid working with these types of stone on purpose?

Yes	No

16. If yes, on average, how many days per week do you spend working with these stone types mentioned in question 14?

Less than 1 day	5 days
2 days	6 days
3 days	7 days
4 days	

17. On average, how many hours per day do you spend working with these stone types mentioned in question 14?

Less than 1 hour	1 – 2 hours
3 – 4 hours	5 – 6 hours
7 – 8 hours	9 – 10 hours
11 – 12 hours	More than 12 hours

18. Do you carry out any of the following activities on <u>Sandstone or any other stone mentioned in question 14</u>? Please select all that apply

Dimensioning stone using handheld saw or a grinder

Dimensioning stone using large saw

Sawing stone e.g. using circular saw or disc cutter

Splitting stone e.g. using hydraulic splitter or chisel

Drilling or boring stone

Dry polishing

Decorative work

Chiselling stone

Grinding or abrading stone

Sandblasting enclosed in chamber

Sandblasting outdoors/not enclosed

Water polishing with diamond pads

19. Do you use any of the following tools or machines while working with Sandstone or any other stone mentioned in question 14? (Tick as many as apply)

Angle Grinder 5”		Large Circular Saw	
Angle Grinder 9”		Combi Hammer/Kangol	
Breaker		Large Circular Saw	
Brushing Tool		Combi Hammer	
Chisel (Pneumatic)		Con Saw	
Chisel (Hand)		Chaser	
Cup Polisher		Hand Punch	
Cylinder Polisher		Hand Pick	
Core Drill		Drill	
Water Polisher		Sandblasting chamber	
Portable Sandblaster			
Other tools (please specify): ___________________________________			

20. Which tools from question 19 do you use most frequently when working with <u>Sandstone or other stones mentioned in question 14?</u>

____

21. Do you use any of the following to control and minimise your exposure to dust when working with <u>Sandstone or other stone mentioned in question 14</u>? Select all that apply

Respiratory Protective Equipment. e.g., Dust mask

Ventilation Capture Arm/Hood

Ventilation Booth

On- tool Extraction/Ventilation

On-tool Water Suppression

Water wall

Water Misting

Pre soaking stone

General ventilation/working outdoors

22. Which of the following methods do you use to remove/clean up debris when working with Sandstone or other stone mentioned in question 14? Select all that apply

Blowing eg: Pneumatic exhaust

Sweeping

Vacuum

Water

Other: ____

23. Do you work with any of the following types of stone? Select all that apply

	Yes	**No**
Slate		
Granite		
Marble		
Limestone		
Diorite		
Serpentinite		
Basalt		
Gabbro		
Dolerite		
Other: ______________________		

24. If yes, on average, how many days per week do you spend working <u>with these stone types mentioned in question 23</u>?

Less than 1 day	1 day
2 days	3 days
4 days	5 days
6 days	7 days

25. On average, how many hours per day do you spend working with <u>these stone types mentioned in question 23</u>?

Less than 1 hour	1 – 2 hours
3 – 4 hours	5 – 6 hours
7 – 8 hours	9 – 10 hours
11 – 12 hours	More than 12 hours

26. Do you carry out any of the following activities at work with <u>the stone types mentioned in question 23</u>? Select all that apply

Dimensioning stone using handheld saw or a grinder

Dimensioning stone using large saw

Sawing stone e.g. using circular saw or disc cutter

Splitting stone e.g. using hydraulic splitter or chisel

Drilling or boring stone

Dry polishing

Decorative work

Chiselling stone

Grinding or abrading stone

Sandblasting enclosed in chamber

Sandblasting outdoors/not enclosed

Water polishing with diamond pads

27. Do you use any of the following tools or machines while working with <u>the stone types mentioned in question 23</u>? (tick as many as apply)

Angle Grinder 5"		Large Circular Saw	
Angle Grinder 9"		Combi Hammer/Kangol	
Breaker		Large Circular Saw	
Brushing Tool		Combi Hammer	
Chisel (Pneumatic)		Con Saw	
Chisel (Hand)		Chaser	
Cup Polisher		Hand Punch	
Cylinder Polisher		Hand Pick	
Core Drill		Drill	
Water Polisher (diamond pads)		Sandblasting chamber	
Portable Sandblaster			
Other tools (please specify): ______________________________			

28. Which from question 27 do you use most frequently when working with <u>Limestone or other stones mentioned in question 23?</u>

____

29. Do you use any of the following exposure controls <u>with the stone types mentioned in question 23</u>? Please select all that apply

Respiratory Protective Equipment. e.g., Dust mask

Ventilation Capture Arm/Hood

Ventilation Booth

On- tool Extraction/Ventilation

On-tool Water Suppression

Water wall

Water Misting

Pre soaking stone

General ventilation/working outdoors

30. Which of the following methods do you use to remove/clean up debris when working <u>with the stone types mentioned in question 23</u>? Please select all that apply

Blowing eg: Pneumatic exhaust

Sweeping

Vacuum

Water

Other: ____

<u>SECTION 3 - Your Knowledge of Health and Safety</u>

31. Where do you go for Health and Safety information?

The Health and Safety Authority (HSA)

A Health and Safety Consultant

Supervisor/Manager

The Internet

Newspapers/Newsletters

Colleagues/Peers

Word of mouth at conferences/meetings

Other: ____

32. Do you have any of the following documentation in your workplace?

	Yes	No
Safety Statement		
Safety Procedures and Policies		
Risk Assessments		

33. If yes, who compiled it?

Yourself

A Health and Safety Consultant

Other: ____

34. When is the safety documentation reviewed?

Change in work practice

Purchase of new equipment

Annually

Never

35. On a scale of 1 to 5, with 1 being "Strongly Agree" and 5 being "Strongly Disagree", Please rate how much you agree or disagree with the following statements.

	1	2	3	4	5
I am well-informed about current health and safety legislation.					
If I require information on health and safety I know where to avail of it.					

36. Are you familiar with the Health and Safety Authority (HSA) and its role?

Yes No Unsure

37. Have you ever been inspected by the Health and Safety Authority?

Yes No

38. Have ever received any health and safety training? (If not please move to question 44)

Yes No

If yes, please specify the provider ________________________________

39. When did you last receive training? __________________________

40. Did the health and safety training include information on any of the following? Please tick all that apply.

Health and safety legislation

Safety statement

Workplace hazards

Risk assessments

Ergonomics

Emergency procedures

Protective clothing and equipment

Respiratory protection

Silica Dust Hazards

Control of Dust

Health and safety policies and procedures

All of the above

Other:____

41. Did you receive refresher training?

Yes No

42. Did you receive information on aspects of health and safety related <u>to your work with stone?</u>

Yes No

43. Do you feel that the information you received during your training was covered in enough detail?

Yes No

44. Are you aware of the Safety, Health and Welfare at Work (Chemical Agents) Regulations 2001?

Yes No

45. Do you know what the current Occupational Exposure Limit Value (OELV) for Silica dust is?

Yes No

46. There are various pieces of guidance published by the Health and Safety Executive in the UK aimed at helping employers control the risks posed by stonemasonry dust; are you aware of/or have made use of any of the following?:

- HS(G) 201 'Controlling Exposure to Stonemasonry Dust: Guidance for Employers.

Yes No

- INDG315 'Stone Dust and You: Guidance for Stonemasons'

Yes No

- Control of Substances Hazardous to Health regulations (COSHH Regs)

Yes No

- COSHH Silica Essentials

Yes No

47. If yes, where did you get/hear of these documents?

The Health and Safety Authority (HSA)

The Health and Safety Executive UK (HSE)

A Health and Safety Consultant

Supervisor/Manager

The Internet

Other : ____

SECTION 4 – Workplace Hazard Identification

48. How often do the following aspects of the workplace environment interfere with your ability to work effectively? Please tick each item.

	Always	**Often**	**Sometimes**	**Seldom**	**Never**
Noise					
Dust					
Vibration					
Fumes					
Heat					
Cold					
Bad Lighting					
Cleaning of workplace					
Awkward postures					
Workplace layout					
Heavy Lifting					

49. Please tick the level of risk you associate with each of the following stonemasonry activities

<u>Examples of exposure controls include</u>: Dust mask or other respiratory protective equipment (RPE) or engineering controls for example: Ventilation/Extraction arm, on tool Extraction/Ventilation, ventilation Booth, Water Suppression.

	No Risk	Low risk	Moderate Risk	High Risk
Cleaning Work Area				
Cleaning Overalls				
Hand Chiselling Stone **No** Exposure Controls				
Pneumatic Chiselling Stone **No** Exposure Controls				
Cutting Stone **No** Exposure Controls				
Polishing Stone **No** Exposure Controls				
Hand Chiselling Stone **With** Exposure Controls				
Pneumatic Chiselling Stone **With** Exposure Controls				
Cutting Stone **With** Exposure Controls				
Polishing Stone **With Wet** Exposure Controls				
Polishing Stone **With Dry** Exposure Controls				
Carrying out Dusty Tasks Outdoors				
Carrying out tasks with **RPE Only (e.g. dust mask only)**				

SECTION 5- Your Health

50. Are you aware of the long term illnesses associated with exposure to silica dust?

Yes No

51. In your opinion, would you say your health is ..... (please tick one)

Excellent Very Good Good Fair Poor

52. How do you rate your current ability to work with respect to the <u>physical</u> demands of your work? (Please tick one)

Very good Rather good Moderate Rather poor Very poor

53. Do you, or have you ever smoked? (If no, please move to question 57)

54. If yes, (at what age) when did you start smoking regularly? ________________

55. Do you still smoke?

56. If no, (at what age) when did you give up smoking? ___________________

57. Have you ever heard of the following respiratory illnesses? Please tick all that apply

Silicosis

Acute Silicosis

Chronic Silicosis

Bronchitis

Emphysema

Asthma

Lung Cancer

58. The following is a list of potential work related illnesses. Please tick either 'Own opinion' if in your opinion you suffer from this work related illness or 'Doctors diagnosis' if it has been diagnosed by a doctor. Please leave blank if this does not apply.

Respiratory Illnesses

	Own Opinion	Doctor's Diagnosis
Repeated chest infections		
Asthma		
Sinusitis		
Bronchitis		
Tonsillitis		
Nasal irritation		
Persistent cough		

Respiratory Illnesses (Long Term)

	Own Opinion	Doctor's Diagnosis
COPD		
Emphysema		
Silicosis		
Lung Cancer		

59. In your opinion, what aspect of your work caused your respiratory illness? Please give details. Please leave blank if this does not apply.

____

____

60. Is your work related illness or injury a hindrance to your current job? Please leave blank if this does not apply.

(Tick more than one alternative if applicable)

There is no hindrance/ I have no illnesses
I am able to do my job, but it causes some symptoms
I must sometimes slow down my work pace or change my work schedule
I must often slow down my pace or change my work methods
Because of illness, I feel I am only able to work part-time
In my opinion, I am entirely unable to work

Thank You for Completing this Questionnaire

Please return this questionnaire to me when you are finished and let me know if you have any questions

Contact details: c.healy5@nuigalway.ie, (091) 493403

Appendix D: Worker Intervention Questionnaire

Dear Sir/Madam,

I am a research student studying Occupational Hygiene at NUI, Galway.

I would like to invite you to participate in my research on the subject of controlling silica dust exposure among workers who work with stone. I have decided to carry out this study as there is a limited amount of research conducted in this area in Ireland.

Through your participation, I would like to investigate the factors that influence workers to use or not to use equipment such as dust masks and ventilation to reduce their exposure to dust whilst working with stone.

I would greatly appreciate if you would complete the questionnaire enclosed. Most questions are designed to be answered using a tick in a box or rate on a scale of 1-5.

Please be assured that all information you provide is anonymous as you will not be asked to put your name on the questionnaire.

Thanks very much for your time and help with the survey.

Yours Sincerely,

Catherine Healy.

Questionnaire Instructions:

This questionnaire is divided into 4 sections:

Section one is composed of questions about you.

Section two is composed of questions related to your self-reported use of a dust mask/other type of respiratory equipment and other exposure control devices while working with stone e.g. ventilation arms, hoods, on tool extraction and water suppression.

Section three includes questions about the factors which influence you to use or not use exposure control devices whilst working with stone.

Section four includes questions about what you believe to be the impact of dust on your respiratory health from working with stone.

Please tick the box which is representative of the most appropriate response.

Section 1 – About You

61. How old are you?

18 - 25 | 26 - 35
36 - 45 | 46 - 55
56 - 65

62. Gender: Male Female

63. How many hours do you work on average per week? ________Hours

64. How many years have you worked with stone? __________Years

65. How many years have you worked with stone <u>in the OPW</u>? __________Years

66. Which group best describes your role in the OPW?

Stonecutter General Operative

Stonemason

If other, please specify ____

67. Do you smoke?

Yes No

Section 2 - Self-Reported Use of Exposure Control Devices

Exposure Control Devices include: dust mask or other respiratory equipment or other exposure controls like ventilation/extraction arm, ventilation/extraction hood, on tool ventilation/extraction, water suppression.

68. If you are required to use exposure control devices, what would be the <u>main reason</u> you use exposure control devices when you work with stone? (Please tick one)

To protect my health	Because my co workers tell me to
It looks professional	Because my family tell me to
It makes my work more comfortable	Because it is my workplace policy
It makes my work easier to do	Because my supervisor tells me to

69. Who is responsible for my safety?

People above my supervisor	My co workers
Site foreman	I am
My supervisor	

70. Who enforces the use of exposure control devices when you work with stone? (Tick one)

People above my supervisor	My co workers
Site foreman	My family
My supervisor	Nobody does
I do	

71. If you used a **dust mask** or **other respiratory equipment** during the past year, which of the following best describes the type worn the majority of the time? (Please Tick one)

One strap dust mask	Air- Fed Hood
Two-strap disposable dust masks	Not applicable, did not wear respiratory protection
Full-face mask with replaceable cartridges	Piece of fabric covering the face
Half mask with replaceable cartridges	Wore something else for protection Please explain ________________________________

72. If you used **other exposure control devices** to control your exposure to dust during the past year, which of the following best describes the type used?

Dust receiving/capture arm	On tool extraction/ventilation
Dust receiving canopy hood	On tool stream of water
Partial enclosure booth	Water misting
Walk in dust extraction booth	Other Please explain ________________________________

73. On the average during the past year, how often did you use exposure control devices when working with **power tools and sandstone or granite**?

Never (0% of time)	Very Often (51-75% of time)
Seldom (1-5% of time)	Most Always (76%-99% of time)
Sometimes (6-25% of time)	Always (100% of time)
Often (26-50% of time)	

74. On the average during the past year, how often did you use exposure controls when working with **power tools and limestone or lime mortar**?

Never (0% of time)	Very Often (51-75% of time)
Seldom (1-5% of time)	Most Always (76%-99% of time)
Sometimes (6-25% of time)	Always (100% of time)
Often (26-50% of time)	

75. Do you use exposure controls less whilst working outdoors?

Yes No

76. How many years have you been using exposure control devices to control exposure to dust? ________ (Years)

Section 3 - The factors which influence you to use or not use Exposure Control Devices whilst working with stone.

Exposure Control Devices include: dust mask or other respiratory equipment or other exposure controls like ventilation/extraction arm, ventilation/extraction hood, on tool ventilation/extraction, water suppression.

77. Who has the most influence over your use of exposure control devices? (Please Tick One)

My supervisor	My co workers
Site foreman	My family
My supervisor	Myself
The Health and Safety Authority (HSA) or other legislative body	Other Please explain ______________________________

78. What has the most influence on your use of exposure control devices? (Tick one)

Comfort e.g. mask is too hot, straps are uncomfortable, cant breath

Incompatibility with other PPE e.g. goggles, hard hat.

Ability to communicate with co workers

Ability to smoke while working

Ability to see your work

Time it takes to put mask on

Supervisor/co-workers telling me to wear a dust masks

Supervisor/co-workers wearing a dust mask

Protection of my health

Availability of dust masks

Training/Fit testing of dust mask

Exposure control device too noisy

Exposure control device uses too much energy

Other (Please explain)

____

On a scale of 1 to 5, with 1 being "Strongly Agree" and 5 being "Strongly Disagree", Please rate how much you agree or disagree with the following statements.

Exposure Control Devices include: dust mask or other respiratory equipment or other exposure controls like ventilation/extraction arm, ventilation/extraction hood, on tool ventilation/extraction, water suppression.

Strongly Agree	Agree	Neither	disagree	Strongly disagree

Benefits of using exposure control devices.

79. Using exposure control devices when working with stone protects my health.	**1**	**2**	**3**	**4**	**5**
80. Using exposure control devices now when working with stone protects my health in the future.	**1**	**2**	**3**	**4**	**5**

Strongly Agree	Agree	Neither	disagree	Strongly disagree

81. Using exposure control devices now influences my ability to work in the future.	**1**	**2**	**3**	**4**	**5**
82. Using exposure control devices now decreases my chances of having adverse respiratory symptoms such as cough and chest tightness.	**1**	**2**	**3**	**4**	**5**

Negative consequences of using exposure control devices

83. Wearing a dust mask makes me feel claustrophobic.	**1**	**2**	**3**	**4**	**5**
84. Wearing s dust mask makes the air smell bad.	**1**	**2**	**3**	**4**	**5**
85. Using exposure control devices interferes with my vision.	**1**	**2**	**3**	**4**	**5**
86. Wearing a dust mask causes me to get hot while working.	**1**	**2**	**3**	**4**	**5**
87. Wearing a dust mask makes me feel uncomfortable.	**1**	**2**	**3**	**4**	**5**
88. Wearing a dust mask makes it difficult to breath while working.	**1**	**2**	**3**	**4**	**5**
	Strongly Agree	**Agree**	**Neither**	**disagree**	**Strongly disagree**
89. Using exposure control devices interferes with my ability to do my job.	**1**	**2**	**3**	**4**	**5**
90. Wearing a dust mask makes my eyeglasses fog.	**1**	**2**	**3**	**4**	**5**
91. Wearing a dust mask interferes with my smoking habit.	**1**	**2**	**3**	**4**	**5**

92. Using exposure control devices makes it difficult to talk to my co-workers. **1** **2** **3** **4** **5**

93. Using exposure control devices take too much time to use **1** **2** **3** **4** **5**

94. My co-workers do not use exposure control devices so why should I? **1** **2** **3** **4** **5**

95. My supervisor does not use exposure control devices so why should I? **1** **2** **3** **4** **5**

96. I do not use exposure control devices because I am not supplied with them at work. **1** **2** **3** **4** **5**

Strongly Agree	Agree	Neither	disagree	Strongly disagree

97. I have to purchase my own dust mask because my supervisor does not allocate money for the purchase of dust masks at work. **1** **2** **3** **4** **5**

98. An apprentice or other co worker who is not in a supervisory position usually purchases dust masks for work. **1** **2** **3** **4** **5**

99. I am protected whilst using an exposure control device

regardless of whether it
fits or is operating properly 1 2 3 4 5

100. I am sufficiently protected whilst wearing a dust mask that 'seems to fit' even if it has not been fit tested 1 2 3 4 5

101. I do not wear a dust mask because there is no good place to store my dust mask at work 1 2 3 4 5

102. I don't know how to correctly use my recommended exposure control device for my job. 1 2 3 4 5

103. I don't know why I should use an exposure control device for my job. 1 2 3 4 5

	Strongly Agree	Agree	Neither	disagree	Strongly disagree
104. I sometimes use my personal judgement to decide whether or not I need to use an exposure control device	1	2	3	4	5
105. I do not know how to properly maintain my exposure control devices	1	2	3	4	5
106. I do not know how to properly dispose of my dust mask.	1	2	3	4	5

Factors which have a positive influence on my use of exposure control devices

107. I wear a dust mask/ other respiratory equipment because my supervisor allocates money to buy dust masks / other respiratory equipment for work **1** **2** **3** **4** **5**

108. I wear a dust mask/ other respiratory equipment because they are conveniently located at my worksite. **1** **2** **3** **4** **5**

109. I wear a dust mask/ other respiratory equipment because my family encourages me to do so. **1** **2** **3** **4** **5**

110. I wear a dust mask/ other respiratory equipment because my supervisor tells me wear a dust mask/ other respiratory equipment **1** **2** **3** **4** **5**

Strongly Agree	Agree	Neither	disagree	Strongly disagree

111. I wear a dust mask/ other respiratory equipment while working because my co-workers use a dust mask/ other respiratory equipment when working. **1** **2** **3** **4** **5**

112. I wear a dust mask/ other respiratory equipment because my coworkers encourage me to wear a dust mask/ other respiratory equipment when working. **1** **2** **3** **4** **5**

113. I wear a dust mask/ other respiratory equipment while working because my supervisor uses a dust mask/ other respiratory equipment when working. **1** **2** **3** **4** **5**

114. I am more likely to use a dust mask when my family members remind me to do so. **1** **2** **3** **4** **5**

I am legally obliged to wear a dust mask if it is provided. **1** **2** **3** **4** **5**

Section 4 - The impact on my respiratory health from working with stone

On a scale of 1 to 5, with 1 being "Strongly disagree" and 5 being "Strongly agree", Please rate how much you agree or disagree with the following statements.

	Strongly disagree	Disagree	Neither	Agree	Strongly Agree
115. It is likely that I will develop lung damage from working with stone.	**1**	**2**	**3**	**4**	**5**
116. I am more likely to get a lung infection such as pneumonia than workers who do not work with stone	**1**	**2**	**3**	**4**	**5**
117. I believe it is too late for me to protect against the risk of developing lung damage	**1**	**2**	**3**	**4**	**5**
118. I have been exposed to high levels of stone dust earlier in my career so there is no point in protecting myself.	**1**	**2**	**3**	**4**	**5**

119. Older workers who tolerate risks to their own health while working with stone dust encourage unsafe behaviours in younger workers	**1**	**2**	**3**	**4**	**5**
120. I am more likely to develop lung disease (asthma, bronchitis, emphysema) than workers who do not work with stone.	**1**	**2**	**3**	**4**	**5**
121. I am more likely to use exposure controls when I do chores that cause more dust such as polishing stone.	**1**	**2**	**3**	**4**	**5**
122. Being exposed to dust is part of working with stone.	**1**	**2**	**3**	**4**	**5**

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

Please return this questionnaire to me when you are finished and let me know if you have any questions.

Contact details: c.healy5@nuigalway.ie, (091) 493403

Appendix E: Training on hazards associated with RCS

Appendix F: RCS Concertina Card

Appendix G: Workshop Poster

OPW

The Office of Public Works
Oifig na nOibreacha Poiblí

Recommended engineering controls and RPE for tasks in workshop and on-site

IF IT'S SILICA IT'S NOT JUST DUST

Recommended exposure controls for tasks involving sandstone (workshop & on-site)

	Cutting 5", 9" & 12" grinders	Grinding 5" grinder	Cutting water cooled primary saw	Decoration pneumatic & hand chisels
Exposure controls in workshop:	RPE with a minimum protection factor of 40 (3M Versaflo PAPR 1)	Dustie 2 with RPE with a minimum protection factor of 20 (FFP3 disposable dust mask 3 / 3M Versaflo PAPR 1) Use 3M Versaflo PAPR if not using Dustie	Water suppression & wear RPE with a minimum protection factor of 20 (FFP3 disposable dust mask 3 / 3M Versaflo PAPR 1)	Nederman extraction arm 4
Exposure controls on site:	RPE with a minimum protection factor of 40 (3M Versaflo PAPR 1)	Dustie with mobile vacuum unit and RPE with a minimum protection factor of 20. Use 3M Versaflo PAPR if not using Dustie	N/A	RPE with a minimum protection factor of 20 (FFP3 disposable dust mask 3 / 3M Versaflo PAPR 1)

Recommended exposure controls for tasks involving limestone/ lime mortar (workshop & on-site)

	Cutting 5", 9" & 12" grinders and grinding 5" grinder	Cutting water cooled primary saw	Scabbling / brushing pneumatic & hand chisels	Re-pointing
Exposure controls in workshop:	Nederman extraction arm 4	Water suppression	Nederman extraction arm and wear RPE with a minimum protection factor of 20 (FFP3 disposable dust mask 3 / 3M Versaflo PAPR 1)	N/A
Exposure controls on site:	Not required	N/A	RPE with a minimum protection factor of 20 (FFP3 disposable dust mask 3 / 3M Versaflo PAPR 1)	Not required

Respiratory Protective Equipment (RPE) & Engineering Controls

1 3M Versaflo PAPR

2 Dustie shroud

3 FFP3 Dust mask

4 Nederman Extraction Arm

Putting on a dust mask

1. Cup respirator in hand with straps loose.
2. Place respirator onto face (chin first).
3. Pull top strap over and position on top of head.
4. Pull bottom strap over and place below ears.
5. Shape nose clip with fingertips.
6. Carry out a pre-use fit check of the face piece to ensure air does not leak out around the nose.

Typical silica content of materials

Sandstone: 70-100%

Quartzite: 70-100%

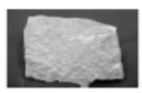
Concrete: 25-70%

Slate: 40%

Red brick: 30%

Granite: 30%

Basalt: 5%



Limestone: 2%

healthandsafetytraining@opw.ie

Appendix H: Training Assessment Questionnaire

Respiratory health in the workplace – respirable crystalline silica (RCS)

Training evaluation and knowledge transfer form

Knowledge review

1. **Give one example of a task that produces high levels of respirable crystalline silica (RCS)**

____

2. **Can RCS be invisible to the naked eye?**

True False

3. **Which has the highest level of silica? Please tick one**

Sandstone Granite

Limestone

4. **Which of the following is important when wearing respiratory protective equipment? Please tick all that apply**

It is fit tested

It is compatible with other PPE e.g. safety goggles

The straps are located in the correct positions

You are outdoors

5. **Name one disease caused by exposure to RCS**

____

6. **What exposure control do you need to use when grinding sandstone with a 5 inch grinder in the workshop?**

____

Training content and delivery

	agree	neither	disagree
1. Did you find the training interesting?	**1**	**2**	**3**
2. Do you have a better understanding of :			
Respirable crystalline silica (RCS)	**1**	**2**	**3**
Respirable crystalline silica in the air	**1**	**2**	**3**
Silica content of different materials	**1**	**2**	**3**
Tasks which produce high levels of RCS	**1**	**2**	**3**
Respiratory diseases from exposure to RCS	**1**	**2**	**3**
Hierarchy of exposure controls	**1**	**2**	**3**
3. Did the training give you ideas about:			
What exposure controls to use for different tasks	**1**	**2**	**3**

4. What did you like most about the training?

____

5. What would you recommend changing?

____

6. **Other comments, observations, suggestions**

____

____

THANK YOU FOR YOUR FEEDBACK

Please return this form to me when you are finished and let me know if you have any questions.

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