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RESEARCH ARTICLE

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Elevated exposures to respirable crystalline silica among engineered stone fabrication workers in California, January 2019–February 2020

Krishna Surasi MD, MPH[1,2] | Brittany Ballen MD[1,3] | Justine L. Weinberg MSEHS, CIH[1,4] | Barbara L. Materna PhD, CIH[1] | Robert Harrison MD, MPH[1,3] | Kristin J. Cummings MD, MPH[1] | Amy Heinzerling MD, MPH[1]

[1]Occupational Health Branch, California Department of Public Health, Richmond, California, USA

[2]Centers for Disease Control and Prevention, Epidemic Intelligence Service, Atlanta, Georgia, USA

[3]University of California San Francisco School of Medicine, San Francisco, California, USA

[4]Public Health Institute, Richmond, Richmond, USA

Correspondence

Krishna Surasi, MD, MPH, Occupational Health Branch, California Department of Public Health, 850 Marina Bay Parkway, Richmond, CA 94804, USA.
Email: krishna.surasi@cdph.ca.gov

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Abstract

Background: Workers fabricating engineered stone face high risk for exposure to respirable crystalline silica (RCS) and subsequent development of silicosis. In response, the California Division of Occupational Safety and Health (Cal/OSHA) performed targeted enforcement inspections at engineered stone fabrication worksites. We investigated RCS exposures and employer adherence to Cal/OSHA's RCS and respiratory protection standards from these inspections to assess ongoing risk to stone fabrication workers.

Methods: We extracted employee personal air sampling results from Cal/OSHA inspection files and calculated RCS exposures. Standards require that employers continue monitoring employee RCS exposures and perform medical surveillance when exposures are at or above the action level (AL; 25 $\mu g/m^3$); exposures above the permissible exposure limit (PEL; 50 $\mu g/m^3$) are prohibited. We obtained RCS and respiratory protection standard violation citations from a federal database.

Results: We analyzed RCS exposures for 152 employees at 47 workplaces. Thirty-eight (25%) employees had exposures above the PEL (median = 89.7 $\mu g/m^3$; range = 50.7–670.7 $\mu g/m^3$); 17 (11%) had exposures between the AL and PEL. Twenty-four (51%) workplaces had ≥1 exposure above the PEL; 7 (15%) had ≥1 exposure between the AL and PEL. Thirty-four (72%) workplaces were cited for ≥1 RCS standard violation. Twenty-seven (57%) workplaces were cited for ≥1 respiratory protection standard violation.

Conclusions: Our investigation demonstrates widespread RCS overexposure among workers and numerous employer Cal/OSHA standard violation citations. More enforcement and educational efforts could improve employer compliance with Cal/OSHA standards and inform employers and employees of the risks for RCS exposure and strategies for reducing exposure.

KEYWORDS

engineered stone, occupational health, personal air sampling, respirable crystalline silica, silicosis

1 | INTRODUCTION

Inhalation of respirable crystalline silica (RCS) is associated with the development of several diseases, including autoimmune disorders, chronic renal disease, lung cancer, pulmonary tuberculosis, chronic obstructive pulmonary disease and, most notably, silicosis.[1] Silicosis is a progressive lung disease that can lead to pulmonary fibrosis, respiratory failure, and eventually death; it can be prevented by reducing or eliminating occupational exposure to RCS. Underscoring importance of prevention is the fact that, apart from lung transplant, no effective treatments for silicosis are available.[2,3] Workers in certain occupations involving silica-containing materials, such as mining, sandblasting, and quarrying, have long been known to be at risk for exposure to RCS and subsequent development of silicosis.[1]

Stone fabrication is the process of cutting and polishing stone, typically for use as countertops. Since 2010, reports from several countries, including the United States, have shown that workers involved in the fabrication of engineered stone, also known as artificial stone or quartz agglomerate, are at high risk for exposure to RCS and the subsequent development of silicosis.[4–7] Silicosis screening in California and Australia has identified disease prevalence of 12%–21% among workers in this industry.[4,8,9]

Of particular concern in this industry has been the higher incidence of accelerated silicosis, a more rapidly progressive form of the disease, particularly in younger workers.[5,10,11] California's first reported outbreak in 2019 included six cases of silicosis diagnosed in workers under age 60, including two fatalities of workers in their 30s.[6] The elevated risk for accelerated silicosis in these workers has been attributed to the high silica content of engineered stone (generally > 90%), compared with natural stone; exposure to large amounts of respirable dust generated from procedures including cutting and grinding engineered stone, especially in the absence of engineering controls such as wet methods and local exhaust ventilation; and the increased cytotoxicity of freshly fractured crystalline silica particles.[12–14] The variability of engineered stone composition, both in terms of silica crystal forms (e.g., alpha quartz, cristobalite, or tridymite) and nonsilica components (e.g., resins, hardening agents, or pigments), further complicates our understanding of what characteristics of these materials may contribute to their potential to cause accelerated silicosis.[15]

To decrease worker RCS exposure and the burden of silicosis, the US Occupational Safety and Health Administration (OSHA) updated the RCS standard in 2016, which was also adopted by the California Division of Occupational Safety and Health (Cal/OSHA).[16,17] The standard requires that employers monitor employee RCS exposures and perform medical surveillance when exposures equal to or exceed the 25 $\mu g/m^3$ action level (AL) and that no employee is exposed to RCS above the 50 $\mu g/m^3$ permissible exposure limit (PEL). RCS exposures are to be measured as 8-h time-weighted averages (TWAs) for comparison with the AL and PEL. Another Cal/OSHA standard that can affect worker exposure to RCS is the respiratory protection standard, which details the minimum steps employers must take to ensure the safe and effective use of respirators in the workplace. However, limited data are available quantifying worker RCS exposure in the stone fabrication industry and employer compliance with the updated RCS standard or respiratory protection standard.

In response to identified cases of silicosis among engineered stone fabrication workers and concern about RCS overexposure, Cal/OSHA initiated a Special Emphasis Program (SEP) to reduce worker exposure to RCS by assessing and enforcing compliance with the RCS standard among employers in this industry.[18] Using data collected at workplaces as part of this program, we sought to summarize RCS exposure levels of workers and describe employer compliance with the updated RCS standard and respiratory protection standard to assess ongoing risk to workers in the stone fabrication industry in California.

2 | METHODS

2.1 | Cal/OSHA inspections

We included in our analysis data from the Cal/OSHA inspections conducted during January 2019–February 2020, of engineered stone fabrication workplaces throughout the state of California as part of its SEP titled Occupational Exposure to Respirable Crystalline Silica, Cut Stone, and Stone Product Manufacturing. For their inspections, Cal/OSHA created a list of workplaces to be considered with the SEP. The list included workplaces that were previously inspected by Cal/OSHA before the SEP but did not have RCS exposure evaluations, workplaces with reports of complaints or illness, and workplaces classified under the North American Industry Classification System (NAICS) category Cut Stone and Stone Product Manufacturing (NAICS code 327991) identified using available employer databases. Workplaces no longer active or that did not fabricate engineered stone were removed from the list; certain workplaces were not inspected because Cal/OSHA's resources were shifted to focus on addressing the COVID-19 pandemic.

During inspections, RCS personal air samples for employees were collected and analyzed according to published methods, with the exception that inspectors were given the option to use parallel particle impactor samplers in place of the prescribed cyclone samplers because of their reliability and convenience.[19] During inspections, Cal/OSHA inspectors asked employers for the number of employees at the job site who are exposed to RCS from their job tasks. This information was recorded in an internal Cal/OSHA database.

2.2 | Data abstraction

We obtained copies of inspection files from all workplaces inspected as part of Cal/OSHA's SEP where RCS personal air sampling was performed. Personal air sample RCS concentrations, sampling times, and crystalline silica type as a percentage of respirable dust by weight for each personal exposure measurement were abstracted from these files. We calculated 8-h TWAs using Cal/OSHA methods. When sampling from an employee over the course of a shift was continuous, we calculated 8-h TWAs by multiplying the measured concentration of RCS by the sampling time and dividing by 8 h. When sampling from an employee over the course of a shift was not continuous, the concentration of RCS from each sampling period was multiplied by the time of that sampling period, and the sum of those products was divided by 8 h. In instances where employees were sampled for more than 8 h, RCS concentration over the entire sampled time was divided by 8 h. The concentration of RCS during the unsampled time was assumed to be zero.[20] For one inspection file that did not contain RCS concentration and sampling time data but did contain 8-h TWAs calculated by Cal/OSHA, we abstracted and used those 8-h TWAs.

Information concerning the employer-reported number of employees at the job site that are exposed to RCS was abstracted from a Cal/OSHA database for those workplaces inspected as part of the SEP in which RCS personal air sampling was performed by Cal/OSHA. Information concerning Cal/OSHA citations for violations of the RCS standard and respiratory protection program standard was obtained from the US Department of Labor inspection information web portal for those workplaces inspected as part of the SEP in which RCS personal air sampling was performed by Cal/OSHA.[17,21,22]

2.3 | Analysis

RCS personal air sampling data from employees were analyzed. All laboratory values reported as lower than the limit of detection were treated as zero. We calculated odds ratios with 95% confidence intervals [CIs] to examine associations between the number of employees at each workplace with exposure to RCS and the following variables: employee exposures above PEL and RCS standard violations. We generated descriptive statistics and calculated odds ratios using R version 4.0.1 (R Foundation for Statistical Computing, https://www.r-project.org).

3 | RESULTS

3.1 | Personal air sampling

Cal/OSHA identified 281 workplaces that appeared to be active sites of engineered stone fabrication. Inspections were started in 106 (38%) workplaces, and among these, RCS personal air sampling had been performed at 47 (44%) workplaces for this analysis. Among these 47 workplaces, the median number of employees sampled was three (range = 1–6). Twenty-four (51%) workplaces had ≥1 worker with an 8-h TWA above the PEL, seven (15%) had ≥1 worker with an 8-h TWA at or above the AL but no workers with an 8-h TWA above the PEL, and 16 (34%) had no workers with an 8-h TWA at or above the AL. The number of employees with employer-reported exposure to RCS from their job tasks was recorded for 44 workplaces; within this group, the median number was 5 (range = 1–30).

In total, 8-h TWAs for RCS from 152 workers were analyzed (Figure 1). Of those 8-h TWAs, 38 (25%) were above

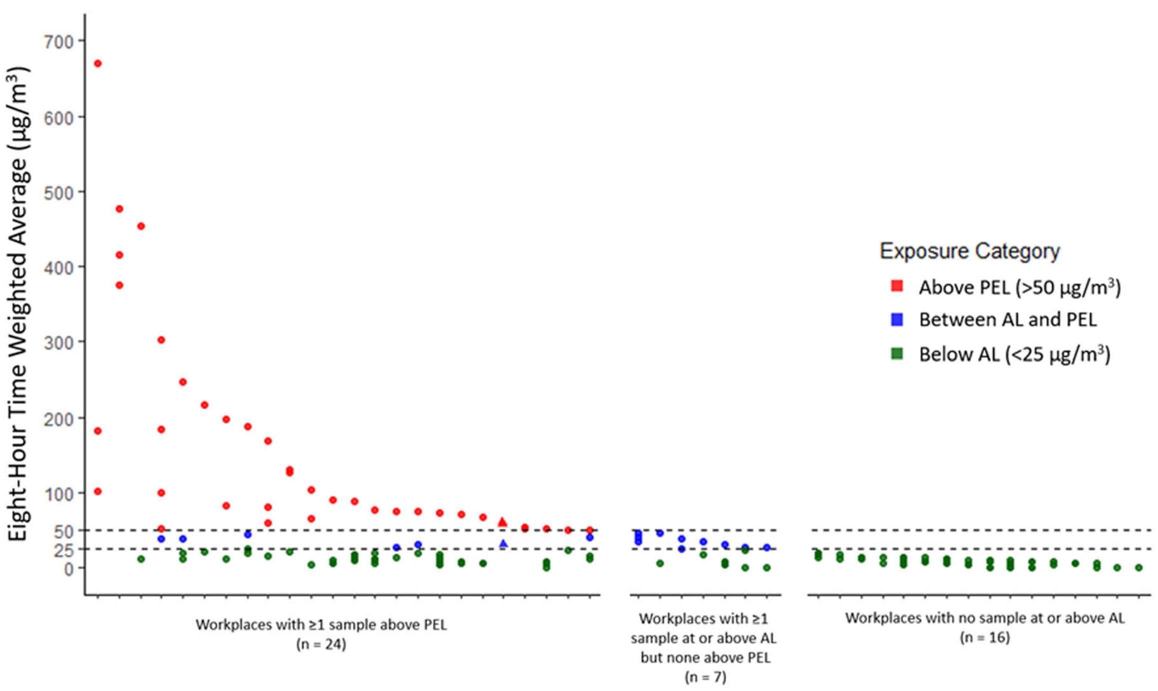

FIGURE 1 Respirable crystalline silica personal air sampling measurements of workers at engineered stone fabrication workplaces inspected by the California Division of Occupational Safety and Health (Cal/OSHA), California, USA, January 2019–February 2020. Dashed lines represent the respirable crystalline silica AL (25μg/m^3) and PEL (50 μg/m^3). Triangle markers represent the Cal/OSHA-calculated 8-h TWAs (*n* = 3) that were abstracted directly from one inspection file that did not contain RCS concentration or sampling time for us to calculate it ourselves. AL, action level; PEL, permissible exposure limit.

PEL (median = 89.7 μg/m^3; range = 50.7–670.7 μg/m^3), 17 (11%) were at or above the AL and below PEL (median = 35.2 μg/m^3; range = 25.5–47.3 μg/m^3), and 97 (64%) had 8-h TWAs below AL (median TWA= 8.5 μg/m^3, range = 0–24.7 μg/m^3). From inspection reports, sampling times for 149 employees were available and the median sampling time for these employees was 412 min (range = 122–582 min).

Among 140 workers with 8-h TWAs for RCS greater than zero, data about different forms of sampled RCS were available for 127. Alpha quartz was detected in samples from 127 (100%) workers, cristobalite was detected in samples from 19 (15%) workers, and tridymite was not detected in samples from any workers. The form that constituted the highest median percentage of total respirable dust by weight per worker sample (or combined samples if sampling was not continuous for that worker) was alpha quartz (median = 15%; range = 2%–74%) followed by cristobalite (median = 0, range = 0%–16%).

3.2 | Employer RCS standard violation citations

Thirty-four (72%) employers were cited for ≥1 violation of Cal/OSHA's RCS standard. The most commonly cited violations were failures to perform exposure assessment (*n* = 32/47, 68%), communicate RCS hazards to employees (*n* = 20/47, 43%), and perform medical surveillance (*n* = 17/47, 36%). Twenty-seven (57%) employers were cited under Cal/OSHA's respiratory protection standard. The most commonly cited violations were failures to establish or maintain a respiratory protection program (*n* = 12/47, 26%), perform fit testing (*n* = 11/47, 23%), and provide medical evaluation (*n* = 7/47, 15%). More details on the standard subsections cited in these violations are presented in Table 1.

3.3 | Associations between employer-reported number of employees at the job site exposed to RCS and measured RCS exposures

Workplaces with fewer than the median of 5 employees with employer-reported exposure to RCS had higher odds of having ≥1 RCS violation citation (OR = 1.9; $p = 0.38$; 95% CI = 0.49–8.0) or ≥1 employee exposure above PEL (OR = 1.5; $p = 0.54$; 95% CI = 0.44–5.0) (Supporting Information: Tables 1 and 2).

4 | DISCUSSION

This analysis represents the first systematic effort to characterize worker exposures to RCS in California's stone fabrication industry and report on employer compliance with the updated RCS standard and respiratory protection standard. Approximately half of the workplaces where personal air sampling was performed had at least one employee with RCS exposure above PEL, the highest of which was 13 times greater than PEL. Findings that 25% of sampled employees had RCS exposures above PEL are similar to results of nationwide OSHA sampling (29% [82/282 personal air samples]) of industries where engineered stone countertop manufacturing may have taken place during the first year that the new standard was enforced (2017–2018).[7]

Our data add to published reports of RCS exposures in stone fabrication workers. Salamon et al. collected a full-shift personal air sample from 51 employees at four workplaces in Italy and reported exposures ranging from <3 to 98 μg/m^3, 13.7% of which were above OSHA PEL.[23] Phillips et al. collected 18 full-shift personal air samples total from 11 employees at four workplaces in the United States and reported exposures ranging from 20 μg/m^3 to 3880 μg/m^3, 77.8% of which were above OSHA PEL.[24] Bartoli et. al collected a personal air sample from 14 employees at two workplaces in Italy and reported exposures ranging from 11 to >519 μg/m^3.[25]

Prevalence of RCS overexposure identified in our study, especially the markedly elevated overexposures, raises alarm given that higher exposures to RCS are thought to contribute to the more rapidly progressive silicosis reported in this industry.[13] All analyzed RCS was in the alpha quartz or cristobalite forms, but we lacked information about the nonsilica composition of sampled dust; more research is needed to understand potential differences in exposure risk from engineered stones with different compositions.

The substantial number of violations of the Cal/OSHA RCS and respiratory protection standards suggests that employers are not adequately implementing exposure controls, including engineering controls (i.e., wet fabrication methods or ventilation), administrative controls (i.e., communication of RCS hazards to employees), and personal protective equipment controls (i.e., respiratory protection program). Most employers in this analysis were cited for not adequately assessing employee exposures, which is required. Those employee exposure results can trigger other components of the RCS standard, such as medical surveillance of employees and respirator use.

Having fewer employees with employer-reported exposure to RCS per workplace was associated with higher odds of RCS standard violations and worker RCS exposures above PEL, although *p* values were high. The possibility exists that the limited sample size was not adequate to detect associations with more confidence. Outreach efforts directed to smaller workplaces about silica risk could be beneficial while more research is done to help clarify workplace characteristics associated with higher RCS overexposures.

Multiple limitations to this report are noted. First, the SEP was interrupted by the COVID-19 pandemic and not all workplaces identified as inspection sites were inspected. Additionally, air sampling was not performed at all workplaces where an inspection was opened, sampling was limited to selected employees over a single shift, and employers were notified in advance that Cal/OSHA would be sampling on those days. Therefore, the results presented here may not be representative of all conditions in this industry in California. Second, because Cal/OSHA 8-h TWA calculations assume no exposure during the unsampled time, results from employees sampled for fewer than 8 h may underestimate exposures. Third, we

TABLE 1 Respirable crystalline silica and respiratory protection standard violation citations from engineered stone fabrication workplaces inspected by the California Division of Occupational Safety and Health, California, USA, January 2019–February 2020.

Standard/section title	Standard or section description	Inspected workplaces where employer was cited for violation (*N* = 47)*N* (%)
§5204 (any section)	Occupational exposure to respirable crystalline silica.	34 (72%)
Exposure assessment	The employer shall assess the exposure of each employee who is or may reasonably be expected to be exposed to RCS at or above the AL.	32 (68%)
Communication of respirable crystalline silica hazards to employees	The employer shall include RCS in the program established to comply with the hazard communication standard.	20 (43%)
Medical surveillance	The employer shall make medical surveillance available at no cost to the employee, and at a reasonable time and place, for each employee who will be occupationally exposed to RCS at or above the AL for 30 or more days per year.	17 (36%)
Permissible exposure limit	The employer shall ensure that no employee is exposed to an airborne concentration of RCS in excess of the PEL, calculated as an 8-h TWA.	16 (34%)
Regulated areas	The employer shall establish and demarcate a regulated area, limit access to that area, and provide appropriate respirators to employees entering that area wherever an employee's exposure to airborne concentrations of RCS is, or can reasonably be expected to be, in excess of the PEL.	14 (30%)
Methods of compliance	The employer shall use engineering and work practice controls to reduce and maintain employee exposure to RCS to or below the PEL, unless the employer can demonstrate that such controls are not feasible. The employer shall also establish and implement a written exposure control plan.	14 (30%)
Respiratory protection	Where respiratory protection is required by this section, the employer must provide each employee an appropriate respirator.	11 (23%)
Housekeeping	The employer shall not allow dry sweeping or dry brushing where such activity could contribute to employee exposure to RCS.	4 (9%)
Recordkeeping	The employer shall make and maintain an accurate record of all exposure measurements taken to assess employee exposure to RCS.	1 (2%)
§5144 (any section)	Respiratory protection	27 (57%)
Respiratory protection program	In any workplace where respirators are necessary to protect the health of the employee or whenever respirators are required by the employer, the employer shall establish and implement a written respiratory protection program with worksite-specific procedures.	12 (26%)
Fit testing	The employer shall ensure that an employee using a tight-fitting facepiece respirator is fit tested before initial use of the respirator.	11 (23%)
Medical evaluation	The employer shall provide a medical evaluation to determine the employee's ability to use a respirator before the employee is fit tested or required to use the respirator in the workplace.	7 (15%)
Use of respirators	The employer shall establish and implement procedures for the proper use of respirators.	4 (9%)
Training and information	The employer shall provide effective training to employees who are required to use respirators.	3 (6%)
Maintenance and care of respirators	The employer shall provide each respirator user with a respirator that is clean, sanitary, and in good working order.	1 (2%)

Abbreviations: AL, action level; NIOSH, National Institute for Occupational Safety and Health; PEL, permissible exposure limit; RCS, respirable crystalline silica; TWA, time-weighted average.

do not have more detailed information about the occupational or medical history of sampled workers and are unable to link exposure assessments to work history or clinical outcomes. Finally, we do not have information about the engineering controls or personal protective equipment used by sampled workers, which limits conclusions we can draw about the effectiveness of techniques designed to decrease the amount of RCS generated or the amount of RCS that enters workers' lungs if respiratory protection is correctly used.

Despite these limitations, these findings, in conjunction with numerous silicosis cases identified among workers in this industry, suggest that widespread overexposure to RCS is occurring among workers fabricating engineered stone.[4,26,27] Employers in the stone fabrication industry should comply with applicable state or federal OSHA standards, including measuring employee RCS exposure levels and implementing effective controls as needed to bring levels below the AL and PEL or lower. To achieve this goal, comprehensive preventive programs that include educational efforts and workplace interventions are needed.[28–30] More research concerning types of work activities that pose the highest risk for RCS exposure and types of engineering controls that effectively decrease this exposure would inform employer guidance on how to best protect workers. Overall, the high exposure levels and prevalence of Cal/OSHA standard violations raise concern about reliance on engineering, administrative, and PPE controls to adequately protect workers from risks associated with this high-silica content material and suggest that measures higher on the hierarchy of controls (e.g., elimination or substitution) should be adopted to protect workers from risks for this high-silica content material.[31]

Given that these inspections were limited to California, conducting similar investigations in other jurisdictions may be valuable. Nationwide efforts, such as improved silicosis surveillance and an OSHA SEP focused on this industry on the national level, could help quantify the risk for workers in the stone fabrication industry nationwide and prioritize prevention efforts.

AUTHOR CONTRIBUTIONS

Conception or design of the work: Krishna Surasi, Barbara L. Materna, Robert Harrison, Kristin J. Cummings, and Amy Heinzerling. *The acquisition, analysis, or interpretation of data for the work*: Krishna Surasi, Brittany Ballen, Justine L. Weinberg, Robert Harrison, Kristin J. Cummings, and Amy Heinzerling. *Drafting the work or revising it critically for important intellectual content*: Krishna Surasi, Brittany Ballen, Justine L. Weinberg, Barbara L. Materna, Robert Harrison, Kristin J. Cummings, and Amy Heinzerling. Final approval of the version to be published: Krishna Surasi, Brittany Ballen, Justine L. Weinberg, Barbara L. Materna, Robert Harrison, Kristin J. Cummings, and Amy Heinzerling. Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Krishna Surasi, Brittany Ballen, Justine L. Weinberg, Barbara L. Materna, Robert Harrison, Kristin J. Cummings, and Amy Heinzerling.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DISCLOSURE BY AJIM EDITOR OF RECORD

John Meyer declares that he has no conflict of interest in the review and publication decision regarding this article.

DATA ACCESSIBILITY

Research data are not shared.

INSTITUTION AND ETHICS APPROVAL AND INFORMED CONSENT

This activity was reviewed by the Centers for Disease Control and Prevention (CDC) and was conducted consistent with applicable federal law and CDC policy (45 C.F.R. part 46, 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.).

ORCID

Krishna Surasi http://orcid.org/0000-0002-9859-629X
Kristin J. Cummings http://orcid.org/0000-0002-5422-9199
Amy Heinzerling http://orcid.org/0000-0001-8808-3004

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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