ENVIRONMENTAL HEALTH
& ENGINEERING, INC.

RADIATION DOSE OF WORKERS DURING FABRICATION OF GRANITE

EXECUTIVE SUMMARY

Multiple studies have been published demonstrating that exposures to both radon and direct radiation from granite countertops are very low, and that this is not an issue of concern for homeowners (Allen et al., 2010; Chen et al., 2010; Myatt et al., 2010; Llope, 2011; Allen et al., 2013). Recently, the U.S. Environmental Protection Agency (EPA) presented an abstract that included some exploratory research pertaining to certain occupational exposure scenarios related to granite, namely quarry workers and fabricators. In this white paper, we sought to investigate this issue in-depth and conducted research to evaluate the radiation dose of workers during fabrication of granite. Specifically, for workers who quarry, cut, and finish granite stone, if exposures to respirable dust and respirable crystalline silica from granite are appropriately controlled, as required under existing regulations, are radiation doses also controlled appropriately?

KEY FINDINGS

Radiation Dose of Workers During Fabrication of Granite

- Radiation doses due to fabrication of granite are very low, and well below both occupational standards (5,000 mrem/year) and limits to the general public (100 mrem/year).
- Workers exposed to granite dust concentrations at the Occupational Safety and Health Administration (OSHA) respirable dust permissable exposure limit (PEL) of 5 milligram per cubic meter (mg/m^3) had an estimated radiation dose of only 8.7 mrem/year, even assuming they spent their entire 2,000 hour work year only working with granite and were exposed to dust at the OSHA limit the entire time.
- Workers exposed to respirable granite dust concentrations at the OSHA silica PEL would have an expected radiation dose of only 1.4 mrem/year, again with very conservative (i.e., health-protective) assumptions (2,000 hour work year only working with granite stone and at the OSHA silica limit).

CONCLUSION

Based on EH&E's review of available data and radiation dose modeling, occupational exposures and health risks related to radiation for granite fabricators are insignificant, i.e., below average background levels.

INTRODUCTION

Humans are exposed to low levels of ionizing radiation as part of their daily lives. The NCRP has estimated that for the U.S. population, the annual average dose of radiation is 620 mrem (NCRP 2009). One half of the exposure (310 mrem) comes from naturally occurring background sources while 48% (300 mrem) is due to medical procedures. NCRP also estimated that industrial and occupational sources make up less than 0.1% of the total exposure, while consumer sources comprise 2% of the total exposure.

It is well known that granite stone is a source of low level of ionizing radiation, but this has been demonstrated to be well below any level of concern from an exposure and health standpoint for homeowners (Myatt et al., 2010; Llope 2011; Chen et al., 2010; Allen et al., 2013). For workers whose primary tasks include quarrying and cutting granite, their doses due to ionizing radiation from granite have not been characterized. Therefore, the goal of this study was to characterize the radiation dose of granite workers in U.S. fabrication shops.

In order to calculate the dose from airborne dust exposures for these workers, we first took a broad approach and asked, "If worker exposure to airborne dust is controlled to existing occupational limits, assuming all of the airborne dust is from granite, is radiation dose also controlled?" By assuming that all of the airborne dust is granite, and exposures occurred at the maximum allowed by law, we are assuming a worst-case scenario. After these initial sets of analyses were completed, we further explored this using two other sets of data: silica and dust measurements from fabrication shops, and occupational limits for silica exposure.

METHODS

Calculating Radiation Dose at the OSHA Respirable Dust Limit

We calculated radiation dose using methodology developed by the International Commission on Radiological Protection (ICRP) and detailed in ICRP Publication 68 (ICRP 1994a). The calculations are done in three steps, described briefly in the following sections.

Step 1. Determining Airborne Activity Concentrations: The first step for determining the radiation dose of airborne granite requires two pieces of information: the amount of respirable granite in the air and the radiological activity of that granite, known as the specific activity. Combining these two pieces of information yields the airborne activity concentration for the granite, as shown in the following formula:

$$\text{Airborne Activity Concentration (Bq/m}^3\text{)} = \text{Respirable granite concentration (mg/m}^3\text{)} \times \text{Specific Activity (Bq/kg)}$$

Respirable Granite Concentration (mg/m^3): The first part of the formula requires knowing the mass of granite per unit volume of air. There is limited information available on the respirable amount of granite in air during work at fabrication shops (respirable simply refers to the size fraction of the dust that is small enough to enter the body during breathing). Therefore, in our first analysis, we used OSHA's occupational exposure limit for respirable dust in the air, which is 5 mg/m^3, and assumed that all of the airborne dust is from granite.

Specific Activity (Bq/kg): The second part of the formula requires knowing the radioactivity content of the airborne granite. We used information published in peer-reviewed literature to obtain this information. A study of 80 samples of granite was conducted that reported the activity concentrations for a wide range of granite colors and types (Myatt et al., 2010). For dose modeling, three series are needed: potassium, uranium and thorium. The average activity concentrations presented by Myatt et al., for each of the series, is presented in Table 2.

TABLE 2 Specific Activity of Various Granite Samples

Series	Average Concentration (Bq/kg +/- SD)
Potassium	1513 +/- 454
Uranium chain	136 +/- 162
Thorium chain	66 +/- 62

Step 2. Setting Exposure Factors: In order to calculate radiation dose, some assumptions need to be made about both the number of work hours in a typical year and an individual's breathing rate. We estimated exposure for two scenarios. The first is an unrealistic work scenario that allows us to calculate a 'worst-case' scenario in which the worker spends their entire year working with granite. In that scenario, we assumed that a worker is fabricating stone for eight hours per day, five days per week, for every work day in a year. This results in 2,000 hours spent working with granite. The second scenario we used assumed 1,000 hours of exposure in a year to account for time not spent actively fabricating stone (e.g., includes time for other work activities, shift breaks, switching out materials to work with, and lunch breaks). For both scenarios, we utilized a breathing rate of 1.2 m^3/hr for the worker, as specified in ICRP Publication 66 (ICRP 1994b).

Step 3. Calculating Radiation dose: Radiation dose was calculated using a standard method developed by ICRP (ICRP 1994a). First, we calculated an airborne concentration that would result in a worker reaching a radiation dose of 5 rem per year, assuming the aforementioned exposure factors, and then we scaled the results based on the results from Step 1. To do this, we used the reference values in ICRP 68 for the isotopes in the uranium and thorium series and potassium 40 to calculate the effective derived air concentration (DAC) for each series, incorporating dose conversion factors for sensitive organs in the body. The ICRP 68 dose conversion factors (DCF) for a series are equal to the total of each isotope in the series weighted by the fraction of activity present in the series. The most conservative lung absorption type (F, M, or S) was used when choosing the DCF for each member of the series and no respiratory protection is assumed to be used by the worker.

Interpreting Radiation Dose

Radiation dose was calculated in units of millirem per year (mrem/year). This is a standard exposure metric and can be used to compare the estimated dose for granite workers to published 'safe' levels of exposure. A list of relevant guideline values used in this study is presented in Table 3.

TABLE 3 Annual Limits of Radiation Dose

Radiation Limit	Organization	Note	Reference
5 rem/yr (50 mSv/yr)	OSHA	Annual ionizing radiation dose limit for workers in the U.S.	(OSHA 1996)
100 mrem/yr (1 mSv/yr)	NRC	Annual total effective dose equivalent to individual members of the public from a licensed operation	(NRC 2002)
100 mrem/yr (1 mSv/yr)	NCRP	Recommended annual radiation dose limit for individual members of the public from all radiation sources other than natural background and the individual's medical care	(NCRP 1993)
100 mrem/yr (1 mSv/yr)	ICRP	Annual radiation dose limit for situations having societal benefit, but without individual direct benefit, and there is no information, no training, and no individual assessment for the exposed individuals in normal situations	(ICRP 2005)
100 mrem/yr (1 mSv/yr)	IAEA	Annual radiation dose limit for members of the public that are exposed to a given source or practice	(IAEA 2003)

OSHA	Occupational Safety and Health Administration
NRC	Nuclear Regulatory Commission
NCRP	National Council on Radiation Protection and Measurements
ICRP	International Commission on Radiological Protection
IAEA	International Atomic Energy Agency
mrem/yr	millirem per year
mSv/yr	millisievert per year

As seen in Table 3, OSHA has an occupational exposure limit of 5 rem/year for ionizing radiation. The NRC, NCRP, the ICRP, and the International Atomic Energy Agency (IAEA) all have a radiation dose limit of 100 mrem/yr for members of the public (NRC 2002; NCRP 1993; ICRP 2005; IAEA 2003). Finally, the NRC also has an occupational radiation limit of 5 rem/yr for radiation workers.

Calculating Radiation Dose at the Silica Dust Limit

In addition to calculating the radiation doses for the respirable dust occupational standards (5 mg/m^3, assuming all dust is granite dust), doses were also calculated using the occupational limit for silica and data from previously published studies of the U.S. granite industry. In order to calculate the radiation doses associated with two relevant silica limits (the OSHA PEL and the American Conference of Governmental Industrial Hygienists [ACGIH] Threshold Limit Value [TLV]), a way to convert a measured respirable silica concentration to a respirable granite dust concentration was required. Effectively, what we are asking is, "If we have a known amount of silica in air, how much respirable granite dust in air does that silica concentration correspond to?"

The following simple equation can be used to estimate the amount of respirable granite dust from measured, respirable crystalline silica concentrations in air:

Respirable granite dust in air (mg/m^3) = Measured silica concentration (mg/m^3)/Percent of crystalline silica in granite sample

In order to estimate the percent silica in respirable granite dust, data were obtained from OSHA's Chemical Exposure Health Data database (http://www.osha.gov/opengov/healthsamples.html). This OSHA database contains industrial hygiene samples collected as part of OSHA's compliance monitoring programs (OSHA 2013). Using these data, we determined that the overall average percent of crystalline silica in granite dust samples is 10.6%

This 10.6% value was used to calculate the expected respirable granite dust concentration, given a specific crystalline silica concentration or occupational limit, where there was no reported percent silica value already given. For example, the OSHA PEL for 10.6% silica is 0.084 mg/m^3. If this much silica was in the air, then we would expect 0.80 mg/m^3 of granite in the air:

0.084 mg/m^3 (OSHA Silica PEL) / 10.6% (percent of crystalline silica in granite) = 0.80 mg/m^3 respirable granite

Calculating Radiation dose from Measurements in Fabrication Shops

In addition to modeling doses at occupational limits, we calculated radiation dose using actual measurements in fabrication shops. Several studies report the concentration of either granite or silica in the air of fabrication shops. When the amount of granite in air is reported, we simply used the ICRP 68 methodology described in Steps 1 – 3 to calculate a dose. When only silica concentrations are reported, we used the method described in the previous section to first estimate how much granite was in the air, assuming 10.6% of silica in granite, and then used Steps 1 – 3 to calculate dose. Finally, if a study reported percent silica concentrations, we used the reported percent silica value instead of our estimated value of 10.6%.

RESULTS

Radiation Dose at OSHA Respirable Dust PEL

Our analysis demonstrates unequivocally that if airborne dust is controlled to OSHA regulations, then radiation dose is controlled (Figure 5). For granite dust concentrations at the OSHA respirable dust PEL of 5 mg/m^3, we estimated a radiation dose of 8.7 mrem/year for a worker working a full 2,000-hour work year. This value is 500 times less than the occupational limit and 10 times less than the limit for the public of 100 mrem/year listed in Table 3. If the worker is only spending one-half of his time working with granite stone, then their radiation dose would be 4.3 mrem/year. We further extended this analysis and estimated the dose if we used the maximum activity concentrations reported by Myatt et al. 2010 and had a worker fabricating this hypothetical stone 2,000 hours per year at the OSHA respirable dust limit. The maximum dose under this unrealistic scenario (48.7 mrem/year) is still well-below OSHA's occupational limit and the 100 mrem/year limit for the public. Our analysis is conservative (i.e., health-protective) because we assumed that the granite dust concentrations were equal to the occupational exposure limit. In other words, we assumed that all of the airborne dust at the OSHA limit was from granite, and had the potential for radioactivity.

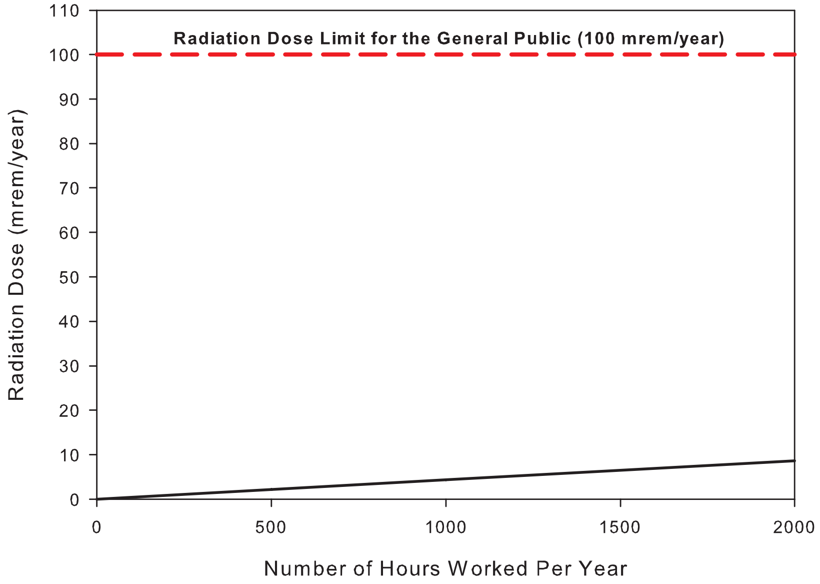

FIGURE 5. Comparison of Radiation Dose from Exposure to OSHA Respirable Dust PEL and the Radiation Dose Limits for the General Public.

Radiation Dose at Silica Limits

Our analysis also showed that if silica is controlled to either the OSHA PEL (assuming 10.6% crystalline silica) or the ACGIH silica TLV, then the resulting radiation dose from the granite dust is very low (Table 4). If silica is controlled to the OSHA silica PEL, then a worker who spends their entire year working with granite would have an expected radiation dose of 1.4 mrem/year. This is well below the 100 mrem/year standards. If we look at exposure to a worker exposed at the ACGIH silica TLV for an entire work year, we see that the resulting radiation dose due to granite dust is 0.4 mrem/year. This is also well below the 5,000 mrem/year occupational and public limits.

TABLE 4 Radiation Dose from Granite at Different Silica Exposure Limits

Occupational Standard	Respirable Silica Concentration at OEL (mg/m^3)	Respirable Granite Concentration at OEL (mg/m^3)	Radiation dose (mrem/year)	
			2,000 hour work year	1,000 hour work year
OSHA Silica PEL - assuming 10.6% silica	0.084	0.80	1.4	0.7
ACGIH Silica TLV	0.025	0.24	0.4	0.2

In addition to calculating radiation doses from the various occupational exposure limits, we also calculated radiation doses from studies of granite fabricators found in the peer-reviewed literature. Table 5 contains the range of calculated radiation doses (and other parameters of interest) from studies of granite fabricators published within the last 15 years (Simcox et al., 1999; Wickman and Middendorf, 2002; Fairfax and Oberbeck, 2008; Sirianni et al., 2008; Phillips et al., 2013).

TABLE 5 Range of Radiation Doses Calculated from Studies in the Peer-reviewed Literature

Study	Percent Silica (%)	Crystalline Silica Concentration (mg/m³)	Respirable Granite Concentration (mg/m³)	Radiation dose (mrem/year) 2000 hour work year	Radiation dose (mrem/year) 1000 hour work year
Simcox et al., 1999	Not Reported	<0.02 – 0.77	<0.19 – 7.29	<0.33 – 12.64	<0.16 – 6.32
Wickman and Middendorf, 2002	20	0.02 – 0.25	0.07 – 1.26	0.13 – 2.18	0.07 – 1.09
Fairfax and Oberbeck, 2008	5.2 – 20.4	Not Reported	0.09 – 3.07	0.16 – 3.14	0.08 – 1.57
Sirianni et al., 2008	Not Reported	BDL (<0.005)	<0.05	<0.08	<0.04
Phillips et al., 2013	8 – 27	0.02 – 3.88	0.07 – 48.5	0.13 – 84.07	0.06 – 42.03

Looking at Table 5, we found that the percent silica composition of respirable granite samples ranged from 5.2% to 27%. For measured crystalline silica concentrations, values ranged from below detection limit (BDL) to 3.88 mg/m^3. Respirable granite dust concentrations ranged from <0.05 to 48.5 mg/m^3. The calculated radiation doses from these studies were all well below the radiation dose limits, even for workers spending an entire working year (2000 hours) fabricating in the dustiest granite shops reported in the literature.

CONCLUSIONS

For granite workers who are exposed to respirable granite dust at the OSHA silica PEL, their expected radiation dose would be only 1.4 mrem/year, even using an unrealistic assumption that they spent their entire 2,000-hour work year working only with granite. This value of 1.4 mrem/yr is well below all of the established occupational limits (5,000 rem/year) as well as limits designed to protect the general public (100 mrem/year). If the worker spent 1,000 hours working with granite, their expected radiation dose would be 0.7 mrem/year. Furthermore, if the workers worked in an area where respirable silica concentrations were controlled down to the ACGIH TLV, their expected radiation dose would be lowered to 0.4 mrem/year for the 2,000-hour work year and 0.2 mrem/year for the 1,000-hour work year. Even if we assume that workers were fabricating granite 8 hours per day, 5 days per week for a full working year (2000 hours), and exposed to granite dust at the OSHA respirable dust limit of 5 mg/m^3, the resulting radiation dose would only be 8.7 mrem/year. This exposure scenario is still much lower than the 5,000 mrem/year occupational limit and the 100 mrem/year limit to the general public.

Five recent studies of granite fabricators have been published containing either measurements of crystalline silica or respirable granite dust concentrations. We calculated the range of radiation doses across these studies, based upon the published sampling data. We determined that the maximum radiation dose across all studies was 84.07 mrem/year, again using an unrealistic, but health-protective, assumption that the worker worked 2,000 hours in an environment that exceeded the OSHA dust and silica limits for the entire year. All of these calculated radiation doses are very low, and are much lower than the occupational exposure limits and radiation standard for the general public put forth by various agencies.

In conclusion, when occupational exposure to dust and/or silica are controlled below OSHA limits, and even in shops that use 'dry' cutting methods where these limits may be exceeded, this analysis shows that radiation doses are well below radiation limits designed to be protective of health for workers and the general public.

REFERENCES

Allen, J. G., Zwack, L. M., MacIntosh, D. L., Minegishi, T., Stewart, J. H., & McCarthy, J. F. (2013). Predicted indoor radon concentrations from a Monte Carlo simulation of 1 000 000 granite countertop purchases. Journal of Radiological Protection, 33(1), 151.

Chen, J., Rahman, N. M., & Atiya, I. A. (2010). Radon exhalation from building materials for decorative use. Journal of environmental radioactivity, 101(4), 317-322.

Fairfax, R., & Oberbeck, B. (2008). OSHA Compliance Issues: Exposure to Crystalline Silica in a Countertop Manufacturing Operation. Journal of occupational and environmental hygiene, 5(8), 81-85.

IAEA. (2003). Safety Series No. 115, International Basic Safety Standards for Protection Against Ionizing Radiations and for the Safety of Radiation Sources. Vienna: International Atomic Energy Agency.

ICRP. (2005). 2005 Recommendations of the International Commission on Radiological Protection: Summary of the Recommendations (Draft). Stockholm, Sweden: International Commission on Radiological Protection.

ICRP. (1994a). Dose coefficients for intakes of radionuclides by workers. ICRP Publication 68. Ann. ICRP 24(4).

ICRP. (1994b). Human respiratory tract model for radiological protection. ICRP Publication 66. Ann. ICRP 24(1–3).

Llope, W. J. (2011). Activity concentrations and dose rates from decorative granite countertops. Journal of environmental radioactivity, 102(6), 620-629.

Myatt, T. A., Allen, J. G., Minegishi, T., McCarthy, W. B., Stewart, J. H., Macintosh, D. L., & McCarthy, J. F. (2010). Assessing exposure to granite countertops—part 1: Radiation. Journal of Exposure Science and Environmental Epidemiology, 20(3), 273-280.

NCRP. (2009). Report No. 160 Ionizing Radiation Exposure of the Population of the United States. National Council on Radiation Protection and Measurements (NCRP), Bethesda, MD.

NCRP. (1993). Limitation of Exposure to Ionizing Radiation. Bethesda, MD: National Council on Radiation Protection and Measurements.

NRC. 2002. Standards For Protection Against Radiation: Subpart D--Radiation Dose Limits for Individual Members of the Public. 10 CFR 20.1301. Retrieved from: http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1301.html

OSHA. 2013. Chemical Exposure Health Data. http://www.osha.gov/opengov/healthsamples.html

OSHA. 1996. Ionizing Radiation Standard. 29 CFR 1910.1096. Retrieved from: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10098

Phillips, M.L., Johnson, D.L., & Johnson, A.C. (2013). Determinants of Respirable Silica Exposure in Stone Countertop Fabrication: A Preliminary Study. Journal of Occupational and Environmental Health. DOI: 10.1080/15459624.2013.789706.

Simcox, N. J., Lofgren, D., Leons, J., & Camp, J. (1999). Silica exposure during granite countertop fabrication. Applied occupational and environmental hygiene, 14(9), 577-582.

Sirianni, G., Hosgood III, H. D., Slade, M. D., & Borak, J. (2008). Particle size distribution and particle size-related crystalline silica content in granite quarry dust. Journal of Occupational and Environmental Hygiene, 5(5), 279-285.

Wickman, A. R., & Middendorf, P. J. (2002). An evaluation of compliance with occupational exposure limits for crystalline silica (quartz) in ten Georgia granite sheds. Applied occupational and environmental hygiene, 17(6), 424-429.