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Radiation and Silica Risks to Granite Countertop Workers

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Abstract

Risks from indoor radon exposure and gamma exposure to homeowners from some granite countertops have been covered by the news media. However, the much more significant risks to granite countertop workers—denoted as fabricators—have received minimal attention in the media and literature. The concentrations of uranium and thorium in granite countertop material range from concentrations similar to natural soil, 1 pCi/g (0.04 Bk/g) to more than one-hundred times higher. The only related work identified in our searches of the literature is our limited work. It appears that granite fabrication shop owners and workers are not informed of the risks.

The objective of the presentation is to inform shop owners, workers, and others of the risks. These risks also apply to other industries where naturally occurring radioactive material (NORM) is present.

An initial field assessment was performed in a granite shop in March 2009 to assess the scope of the issue. Based on the preliminary results, a more extensive field assessment was performed in a granite fabrication shop in October 2009. Sampling was performed for both inhalable dust and respirable dust to allow assessment of the risks from both radiation exposure and crystalline silica. Samples were taken during work on several granite slabs and while using different fabrication procedures over two days. The granite materials were common commercial materials installed in homes and standard fabrication procedures were used. Due to the participants' knowledge of the potential risks a "Respiratory Protection Program" was implemented and special work procedures were implemented to protect the workers for the field assessment.

Multiple samples were analyzed by a commercial laboratory for dust loading, and concentrations of uranium, thorium, and crystalline silica. The assessment shows potentially significant risks to fabricators from airborne dust. The inhalation of the related dust containing uranium, thorium, the uranium and thorium decay-chain radioactive decay products, and crystalline silica results in potential exposures grossly above radiation protection criteria of States and the Nuclear Regulatory Commission and the ACGIH TLV for crystalline silica.

Radiation dose calculations are performed to correspond to the present regulatory framework of the U.S. Nuclear Regulatory Commission and the Environmental Protection Agency. Calculation procedures according to the updated International Commission on Radiological Protection Publication 68 procedures (ICRP 1994), used by Europe, Australia, Canada, et al., were also performed.

Background

Granite is a term for natural stones such as pegmatites, migmatites, gneisses, and schists used for residential countertops, and other indoor trim. Some granites are anatectic alaskites similar to the Rossing uranium deposits. Granite contains uranium (U) and thorium (Th) and their radioactive decay products, and potassium-40 (a radioactive isotope of potassium) (Bernhardt 2009, Kitto 2009, EHE 2008, Salas 2006). All of these radionuclides are what are termed primordial naturally occurring radionuclides which date to the beginning of the universe. Uranium and thorium concentrations range from those similar to normal soil (roughly 0.04 Bq/g, 1 pCi/g) (NCRP 2009) to over 400 pCi/g (15 Bq/g) of uranium; with lower concentrations of thorium (Steck 2009, Kitto 2009). Regulations in the European Community exclude elevated stone from this market with the result that elevated stone comes to the U.S. market (Kovler 2009, EC 1999, CEU 1996). In the U.S. radiation screening limits by some companies of 20 to 35 uR/hr and the supply have resulted in limiting the fabrication and resulting installation of elevated stone to a fraction of the total market being installed in homes, but elevated slabs are still fabricated and installed. All granite contains crystalline silica. It is estimated that about 5 percent of the U.S. market contains granite with rather elevated concentrations of uranium and thorium of about 20 pCi/g or greater. The concentrations of uranium and thorium in the spectrum of granite used are not well documented.

The potential risks to home owners from granite with elevated levels of radioactivity have been covered in both the news and TV media (CBSNews 2008), but there has been minimal coverage of the potential risks to workers/fabricators. The only coverage of radiation risks to fabricators identified, other than presentations and papers be these authors (Bernhardt 2009, Bernhardt 2010, Kincaid 2010), is an article by the Scripts Howard News Service (Wolf 2009) based on an interview of these authors. The Occupational Safety and Health Administration (OSHA) and others have provided some assessments of airborne dust and crystalline silica in the U.S. (Wolf 2009) but there appears to be limited publicity, implementation of controls, and compliance with the ACGIH (ACGIH 2011) or OSHA guidance/regulations (Senchy 2005, Simcox 1999, Wolf 2009, Lofgren 2008).

Scoping studies were performed by the authors in granite fabrication shops in Oklahoma in March 2009. Assessments of the limited results indicated significant potential risks of radiation exposures to fabricators from inhalation of airborne dust, and exposure to crystalline silica (Bernhardt 2009). These scoping results were presented as a work-in-progress poster in 2009 (Bernhardt 2009). Based on the scoping study, a more extensive field study was designed to validate and supplement the results of the scoping studies.

Workers at numerous small shops (about five workers) often are uninformed of the risks and wear no or minimal protective clothing or equipment, except for rubber soled footwear for electric shock protection. If workers wear respiratory protection it generally is dust masks. There are demonstration videos on the internet showing workers with full face beards wearing a respirator while demonstrating equipment. Workers may perform fabrication, smoke, eat, and drink from open containers in the same area without hand-washing facilities. The primary risks from radiation exposure and silica may be in the smaller shops, but there are about five or more shops in most major cities (about 500,000 population). Dust control in larger shops, due to more sophisticated fabrication techniques (e.g., more use of wet techniques and equipment enclosures) may be better than many of the small shops, but there are still risks.

Objective

The objective is to present the work performed documenting the potential risks to granite fabricators from radiation exposure, crystalline silica, and inhalable dust from inhalation of airborne dust. The basic concern is to find a mechanism to inform shop owners and workers of the risks with the anticipation that this will also lead to improved work conditions. This work focuses on the conditions in small shops (i.e., about five fabricators).

Study Design and Implementation

The scoping studies in March 2009 with rather elevated granite (90 pCi/g of uranium) indicated potential risks to fabricators working with elevated granite estimated to represent roughly 5% of the industry. The results of these studies were presented as a Works-in-Progress poster at the June 2009 Health Physics Society Meeting (Bernhardt 2009) and used for developing the follow-up field study in Oklahoma City in October 2009.

The October 2009 field study:

- Included a worker protection program, including a written Respiratory Protection Program and use of half-face respirators, no smoking or eating in the work area, and wearing shop coveralls

- Use of median to low-grade radioactive granite (about 10 pCi/g of uranium) to be representative of roughly 10% of the granite used in the industry

- Fabrication of a vanity countertop using normal fabrication procedures

- Radiation surveys of materials prior to fabrication, field gamma spectroscopy to demonstrate the presence of uranium, thorium, and potassium-40 prior to performing the sampling

- Representatives of OSHA and National Institute Occupational Safety and Health (NIOSH) were invited to attend the study and were present.

- Airborne sampling included extensive side-by-side area samples for "inhalable dust" (NIOSH 0500) to ensure sufficient material was collected for analysis of uranium and thorium, "respirable dust" sampling (NIOSH 0600) for analysis of crystalline silica, and personal "inhalable dust" samples for the full duration of the shift (NIOSH 1994). PVC cassettes and MCE filters were used for samples to be analyzed for uranium and thorium.

- Due to the high dust loading it was necessary to generally change out samples at increments of less than 20 minutes to about an hour. Due to the high dust loading options of both upward facing inlet and downward facing inlet were used for the inhalable dust samples to ensure collection of viable samples, since dust sometimes would flow out of the downward facing inlet. NIOSH 0500 (NIOSH 1994) denotes to limit loading to 2 mg/sample, and the perspective it should be clearly limited to less than 10 mg/sample. With greater loadings loose material accumulates, and if the inlet is oriented down as specified in NIOSH 0500, material may actually flow out like water. Given that dust loadings of 10 mg to more than 100 mg were expected for sampling times as short as 20 minutes, side-by-side samples with the inlets facing both up and down were used to ensure collection of viable samples, without loss of the sampled material.

- The airborne dust samples were analyzed by ALS Lab for dust loading and weight per cubic meter. Of the 66 samples analyzed for dust loading, six were personal samples, 12 were respirable dust, and the remainder were area samples for inhalable dust.

- Analyses for uranium and thorium by ICP-MS were performed on nine (9) inhalable and personal dust samples. Based on the ALS Laboratory sensitivity, 0.031 ug/sample for uranium and 0.63 ug/sample or more for thorium, only samples with sufficient dust to ensure the likelihood of detectable results were analyzed. Initially six (6) sets of two side-by-side samples were composited for analyses to increase the likelihood of detectable results. Subsequently three (3) personal samples with lower dust loadings were analyzed. Nine sets of uranium and thorium results were obtained.

- Six respirable (NIOSH Method 0600) and one personal total dust (NIOSH Method 0500) samples were analyzed for crystalline silica (NIOSH Method 7500). Samples from both wet and dry cutting and grinding were included.

Standards and Guidance for Assessing Impacts

The field study produced measurements of the airborne dust loading with units of mg/m^3 for both inhalable and respirable dust. The most current guidance criteria for dust assessments are the Threshold Limit Values (TLV) of the American Conference of Government Industrial Hygienists (ACGIH), which are updated annually, and are the industrial standard (ACGIH 2011). TLV's are given for inhalable dust, respirable dust, crystalline silica in respirable dust, and uranium in inhalable dust. The criteria for dust and silica are applicable to this study. The ACGIH TLV for uranium is based on soluble uranium and chemical toxicity, not radiological dose implications (ACGIH 2011, NRC 2011). The chemical toxicity of uranium is important and limiting for exposure to pure uranium. But, when both uranium and thorium and all of their radioactive decay products are present, as is the case for granite, the radiation dose becomes the limiting health concern. Furthermore, the chemical toxicity of uranium is more of a threshold toxicity context, whereas the radiation dose is for chronic exposure and stochastic effects. Therefore, the applicable criteria for uranium and thorium are the framework of radiation protection regulations and guides, not the TLV's.

Guidance for Dust and Crystalline Silica

Silicosis is one of the oldest recognized occupational illnesses. It is an irreversible fibrotic lung disease that is disabling and potentially fatal. There is no cure, and treatments are of limited efficacy. The rate of disease progression depends on both the rate of silica deposition and the total amount of silica deposited in the lungs. The disease can develop quickly, but typical latency is years to several decades. Workers exposed to crystalline silica also have greater risk of lung cancer, pulmonary fibrosis, tuberculosis and other mycobacterial infections. The International Agency for Research on Cancer (IARC) considers crystalline silica to be a human carcinogen. ACGIH denotes it as a suspected human carcinogen (ACGIH 2011).

Reports of dust-related lung disease date back to ancient Greece and Rome (Greenberg, 2007). The condition has been known as stonemasons' disease, grinders' asthma, and potters' rot. Although there have been many names for the disease, silicosis has a single cause: inhalation of respirable crystalline silica. Hippocrates described "breathlessness" in miners. Pliny the Elder encouraged miners to "envelop their faces with loose bladders, which enabled them to see without inhaling the fatal dust." In 1690, Lohneiss reported, "the dust and stones fall upon the lungs, the men have lung disease, breathe with difficulty." In 1700, Bernardo Ramazzini, often called the father of occupational medicine, described "miner's phthisis". Peacock and Greenhow first identified silica dust in miners' lungs in the 1860s, and Visconeti named the condition silicosis a decade later.

The first epidemiological link between specific occupations and silicosis came at the turn of the 20th century. Lee Frankl of the Metropolitan Life Insurance Company reported that foundry, quarry, and machine shop workers were absent due to illness 12 to 14 days each year. In comparison, clerks, bookkeepers and butchers lost only 4 to 6 workdays each year to illness. In 1908, Frederick L. Hoffman of the Prudential Insurance Company stated, "the dust-laden atmosphere are [sic] a decidedly serious menace to life and health." He provided an early description of the mechanism of damage seen in silicosis, "dust in any form, when inhaled continuously and in considerable quantities, is prejudicial to health because of its inherent mechanical properties, destructive to the delicate membrane of the respiratory passages and lungs." The Gauley Bridge disaster brought national attention to silicosis in 1930. Tunneling through rock that contained 90% silica, workers experienced an epidemic of acute silicosis. Four hundred drillers died, and many of the remaining workers were disabled. These events led to the U.S. Public Health Service establishing state-based surveillance of occupational diseases.

Incontrovertible evidence of a link between granite dust and silicosis came from Vermont's granite industry (Ashe 1955; Rosenberg 2005). In the first study of its kind, the Vermont Department of Public Health provided free chest X-rays for granite workers at their work sites. The goal of the project was to determine prevalence of silicosis in the workers and to determine whether dust control measures were effective in reducing new cases of silicosis. Both the X-ray program and the dust control measures went into effect in 1937. In 1937 and 1938, 45.3% of the 805 granite workers X-rayed had silicosis. By comparison, in 1954, after dust control measures were in effect, only 19.8% of the workers X-rayed had silicosis. More impressively, not a single case of silicosis was found in a man who worked only in the Vermont granite manufacturing industry after dust controls went into effect in 1937.

As early as the 1940's it was evident that the use of power tools for cutting stone produced risks for silicosis and pulmonary tuberculosis (Hamilton 1943). Mitigation efforts to control dust included improved exhaust ventilation and use of wet cutting (Ashe 1955).

Although silicosis has long been recognized as a result of exposure to crystalline silica dust, occupational exposures receive inadequate regulatory oversight. In 1980, the U.S. Department of Labor estimated that over 1 million workers were still exposed to silica dust. They predicted that 59,000 workers would develop "silica-related pulmonary effects" due to those exposures. More recently, OSHA reported that over 2 million workers are still exposed to crystalline silica. The NIOSH provides a current assessment of the health effects of occupational exposure to respirable crystalline silica (NIOSH 2002).

Exposure to crystalline silica is of special concern in granite fabrication. Beginning in the 1990s, the price of granite counter tops dropped dramatically. Once seen as a luxury decorator feature, granite counter tops became accessible to the average homeowner. Popularity and demand for decorative granite grew phenomenally in response to the more affordable prices. As a result, there are now many more granite shops and many more granite fabricators than a few decades ago. Many of these granite workers are not trained on the respiratory hazards in their workplaces, and many do not utilize engineering controls or respiratory protection. Except for a few locations, such as Washington State and Sacramento, CA, granite fabrication has received very little attention from regulatory agencies.

There are few studies specifically addressing silica exposure in granite fabrication; however, those few studies indicate a cause for concern. Silica exposure during granite fabrication in the state of Washington often exceeded the state's PEL of 0.1 mg/m^3 (Simcox, 1999). Mean exposures during dry processes exceeded the PEL (Permissible Exposure Limits, regulatory term used by OSHA agencies) for all workers monitored. Mean exposures during both wet and dry processes exceeded the TLV.

In 2004, California OSHA (Cal/OSHA) surveyed granite fabrication shops in the Sacramento area (Senchy 2005). Many shops were found to be in violation of Cal/OSHA regulations for exposure to dust and crystalline silica. Numerous citations were also issued for noise exposure and deficiencies in mandatory programs. Based on the findings of those surveys, Cal/OSHA issued a Silica Hazard Alert (Cal/OSHA 2004). That alert was directed to all granite fabrication shops in California at the time. Recommendations included engineering controls (ventilation), wet fabrication processes, and respiratory protection.

Subsequent monitoring of granite fabrication found even higher dust and silica exposures (Bernhardt 2009, Kincaid 2010). Those surveys primarily focused on smaller shops that utilized hand tools. Dust and silica exposures were substantially higher than those reported by Senchy. It is possible that workers' behavior was somewhat more conservative during monitoring by Cal/OSHA. It is also possible that not all shops will have the extremely high dust exposures that were measured by Kincaid. Larger shops with greater financial resources are more likely to have automated equipment that minimizes dust and silica exposure. However, even large shops with excellent dust controls still exceeded the TLV for crystalline silica. And many granite shops operate primarily with hand tools, and without engineering controls or Respiratory Protection Programs.

The ACGIH provides the current TLV's for both inhalable dust and crystalline silica (NIOSH 2011). The ACGIH TLV's for insoluble or poorly soluble particles, not otherwise specified (PNOS) are 10 mg/m^3 for inhalable dust and 3 mg/m^3 for respirable dust. The ACGIH TLV for crystalline silica is 0.025 mg/m^3 for respirable dust. ACGIH does not have a TLV for crystalline silica in inhalable dust. Cal/OSHA has criteria of 0.1 mg/m^3, but does not have a criterion for respirable dust (Cal/OSHA 2004, Senchy 2005).

Radiation Exposure Regulations and Standards

The radiation doses are evaluated based on the regulations of the Nuclear Regulatory Commission (NRC) and guidance of the National Council on Radiation Protection and Measurements (NCRP) (NRC 2011, NCRP 1993). The OSHA radiation regulations are based on the NRC regulations of about 1970 and have not been updated. However, the OSHA regulations (OSHA 2009) and the NRC regulations (NRC 2011) provide compatible definitions to define radiation work places and the applicability of whether occupational radiation regulations or those for the general public should be applied to granite fabricators. The OSHA occupational regulations apply to "restricted areas," where "restricted area means any area access to which is controlled by the employer for purposes of protection of individuals from exposure to radiation or radioactive materials" –29 CFR 1910.1096 (a)(3) (OSHA 2009). Since in many cases the workers, and possibly the owners don't know or admit that they are dealing with material that contains radioactive substances and that results in a radiation risk, the workers don't have specific training and there is not control of access; the occupation regulations are not applicable. The NRC regulations for occupational exposure are focused on areas with explicit controls and in many cases radioactive material licenses. **Therefore, the applicable regulatory framework is the criterion for the general population, which specifies a dose of 0.1 rem/year (NRC 2011, NCRP 1993).** The occupational worker dose criterion of 5 rem/year (NRC 2011, NCRP 1993) is not applicable for this category of fabricators.

Natural uranium and thorium have what are called decay chains. The parent radioactive atom decays to another radioactive atom, down through a series of atoms until reaching a stable atom. Essentially the total mass of natural uranium is represented by uranium-238; however, uranium-235 (a very small fraction of the mass of uranium) and its radioactive decay chain are also present.

When discussing quantities of radioisotopes, it is necessary to distinguish or clarify between the units of mass (grams) and radioactivity (curies or fractions of a curie, measure of the rate of radioactive decays). Over 99% of the mass of natural uranium is due to uranium-238, but uranium-238 and uranium-234 (a decay product of uranium-238) have the same activity. The difference is the radioactive half-life of uranium-234 is more than ten thousand times less than that of uranium-238; therefore a much smaller mass fraction of uranium-234 has the same amount of radioactivity as the uranium-238.

Table 1 shows the principle radioactive decay products for the uranium and thorium decay chains. The parent radionuclides uranium-238 and thorium-232 for the chains decay through a sequence of radionuclides. Due to the distribution of the radioactive half-lives in these decay chains, when confined in material like granite, all of the primary radionuclides of the decay chains have the same concentration of radioactivity (i.e., curies per gram) as the parent radionuclide (e.g., uranium-238). This is termed secular radioactive equilibrium.

The presence of the numerous radioactive decay products makes the assessment of the dose from inhalation of the dust complex. For example, much of the dose from the uranium-238 decay chain results from the thorium-230 decay product (not to be confused with thorium-232). For simplicity, some of the short half-life radionuclides, which have limited significance from inhalation of the dust, are not listed in Table 1. The radon-222 and radon-220 decay products are listed in the table because of the familiarity with radon. These radon isotopes have minimal significance when considering the inhalation of granite dust. The uranium-235 decay chain is present in nature along with the uranium-238 decay chain, but at about one-twentieth of the radioactivity concentration of that for uranium-238.

There is somewhat of a void for radiation protection standards for the granite countertop fabrication industry. The NRC regulations basically apply to radioactive material license operations and provide exemptions for materials below source material concentrations; that is concentrations of uranium and thorium (additive) below 0.05%. This equates to 167 pCi/g of

Uranium-228 Decay Chain		**Thorium-232 Decay Chain**	
Radionuclide	**Half-life**	**Radionuclide**	**Half-life**
U-238	4.47 E9 years	**Th-232**	1.41 E10 years
U-234	2.45E5 years	Ra-228	5.75E5 years
Th-230	77000years	Th-228	1.91 years

Ra-226	1600 years	Ra-224	3.66 days
Rn-222	3.82 days	Rn-220	55.6 seconds
Rn decay products	Very short	Rn decay products	Very short
Pb-210	22.3 years	11 radionuclides, ends stable Pb-208	
Po-210	138 days		
18 radionuclides, ends with stable Pb-206			
U-225, lower concentration, but significant for internal exposure			
U-235	7.04 E8 years		
Pa-231	3.3E4 years		
Ac-227	22 years	14 radionuclides, ends stable Pb-207	

Table 1. The uranium and thorium radioactive decay chains.

uranium-238 or 55 pCi/g of thorium-232, the principal isotopes of uranium and thorium (NRC 2011). The source material exemption applies to the sum-of-fractions for the combination of both uranium and thorium (e.g., 100 pCi/g of U/167 pCi/g = 0.6 and 22 pCi/g of Th/55 pCi/g = 0.4, for a sum of 1). Although some granites have localized concentrations that significantly exceed the source material criterion, the average concentrations in large slabs of granite (45 to 65 square feet) as sold in the U.S. are generally below the criterion (EHE 2008, Kitto 2009, Steck 2009). Many states have regulatory statutes that would allow regulating the granite fabrication industry (e.g., California, Utah, et. al.), but have not initiated such.

The U.S. Environmental Protection Agency (EPA) has saturator authority (possibly the Toxic Substances Control Act, TSCA) (EPA 1976) and has initiated a study, and has a draft report out for review. The OSHA regulations encompass occupational radiation exposure, which have not been updated since the early 1970's, and are tied to the NRC regulations of that era. Furthermore, as previously noted the OSHA occupational radiation exposure regulations are for 'restricted areas where access is controlled for radiation protection.' Furthermore, most OSHA people are not familiar with radiation exposure and standards, and often fall back on applying the OSHA outdated radionuclide PEL's or the PEL for uranium. Due to a lack of familiarity with radioactive materials and uranium OSHA representatives often don't recognize the presence of the radioactive decay chains and the need to do a sum-of-fractions for all of the radioactive decay products of uranium and thorium.

Although several agencies have or could have responsibility for regulatory oversight of granite fabrication, due to knowledge and agency budget constraints there tends to be a void of oversight or enforcement—versus a 'black hole' of over regulation. In summary of this quagmire, it is concluded that the basic present day guidance is 0.1 rem/yr, the criterion for the general population (NRC 2011, NCRP 1993), and there is minimal regulatory oversight.

The field study provided analytical results with concentrations of inhalable dust, uranium, and thorium in mg/m^3. The radiation guidance and biological effects are best assessed as the "effective dose equivalent" (EDE), the summation of the radiation dose to various organs of the body radiologically equivalent to a uniform dose to the total body (NCRP 1993, NRC 2011). The radiation regulations and guidance are given in this framework (NRC 2011, NCRP 1993). The EDE dose is determined by radiation dosimetry and biological modeling, using standard models that have been developed by the ICRP, with extensive input from U.S. radiation professionals over the years (ICRP 1979, ICRP 1994). The OSHA radiation regulations date back to the early

ICRP Committee II models of the 1960's and 1970's. The present NRC regulations, the basic framework in the U.S. today are from the ICRP 30 et al. models (ICRP 1979). The ICRP issued a significant update in both the respiratory and dosimetry models in the 1990's, denoted here as the ICRP Publication 68 dosimetry or related models (ICRP 1994). Although the NRC has not implemented the ICRP Publication 68 dosimetry in its regulations, upon request, it has accepted its use in a license and has recognized its technical validity (NRC 1999). Several states; i.e., Illinois, California, and Utah, have also recognized the ICRP Publication 68 dosimetry, when requests were made for specific licenses. The European Community and most of the other countries of the world (e.g., Canada, Australia, et al.) have adopted the ICRP Publication 68 related dosimetry.

The dose results for the field study are presented using the dosimetry of the present NRC regulatory framework (NRC 2011), using the dose parameters of EPA Federal Guidance Report 11 (EPA 1988) and the updated ICRP Publication 68 dosimetry.

When performing dose calculations or assessing exposures against the DAC all of the primary radionuclides that are present must be considered (see listings in Table 1). For using the DAC (Derived Air Concentration, similar to the PEL), this concept is denoted as the sum-of-fractions, the same as assessing the presence of several toxic materials in industrial hygiene.

Potential Risks to Granite Fabricators, Results of Field Study

Table 2 shows the results of the dust loading measurements during fabrication of a vanity top. The table provides the sample time, volume, dust loading in the cassettes, and concentrations of dust per cubic meter. The samples were taken concurrently during a sequence of granite cutting and grinding operations. The granite was known as Four Seasons, a Bordeaux from Brazil. Based on previous surveys the highest levels of radioactivity had been cut out of the slab, leaving a slab with low to medium levels of uranium and thorium. The final analytical results indicated average concentrations of about 10 pCi/g for uranium (U-238) and about 1.5 pCi/g of thorium (Th-232).

The airborne concentrations in Table 2 are due to processes of dry cutting, grinding, and polishing during fabricating a vanity top. The results are four episodes, with extensive side-by-side sampling and personal sampling during each sequence. Results are given for four periods of work, six personal samples, and 25 area samples.

A time tracking study in the shop indicated that about 65% of a workers day is spent performing the fabrication tasks generating extensive dust. Other tasks including: unloading trucks, moving the granite slabs, marking out the template for cutting, working on tools,

Time	Filter	Sample ID	Run (Min)	Vol (l)	Type Sample	mg/Sample	mg/m^3
9:47	MCE	10-15-11 U	28	83	Inlet Up	19	230
9:57	MCE	10-15-14 U	18	50	Inlet Up	14	280
9:47	MCE	10-15-12 U	28	81	Inlet Up	19	230
9:57	MCE	10-15-13 U	28	81	Inlet Up	17	210
9:47	PVC	10-15-16 P	20	58	Inlet Dn	2.1	36
9:47	PVC	10-15-17 P	20	57	Inlet Dn	4.9	86

9:47	PVC	10-15-Pr 1	28	82	**Personal**	4.1	50
11:14	MCE	10-15-31 U	38	112	Inlet Up	21	190
11:14	MCE	10-15-32 U	38	110	Inlet Up	21	190
11:14	MCE	10-15-33 U	38	110	Inlet Up	19	170
11:14	MCE	10-15-34 U	38	95	Inlet Up	18	190
11:14	PVC	10-15-35 Pr	16	47	**Personal**	86	1800
11:30	PVC	10-15-45 Pr	22	64	**Personal**	16	250
11:14	PVC	10-15-36 P	38	111	Inlet Dn	21	190
11:14	PVC	10-15-37 P	38	110	Inlet Dn	2.4	22
11:30	PVC	10-15-47 P	22	64	Inlet Dn	21	330
12:41	MCE	10-15-51 U	79	233.8	Inlet Up	30	130
12:41	MCE	10-15-52 U	79	229.6	Inlet Up	38	160
12:41	MCE	10-15-53 U	79	229.6	Inlet Up	24	100
12:41	MCE	10-15-54 U	79	221.5	Inlet Up	22	98
12:55	PVC	10-15-55 Pr	26	76.6	**Personal**	24	310
1:47	PVC	10-15-59 Pr	14	41.2	**Personal**	1.1	26
12:55	PVC	10-15-56 P	66	195	Inlet Dn	5.8	30
12:55	PVC	10-15-57 P	66	193.2	Inlet Dn	15	80
2:34	MCE	10-15-71 U	47	140	Inlet Up	48	340
2:34	MCE	10-15-72 U	47	137	Inlet Up	62	450
2:34	MCE	10-15-73 U	47	138	Inlet Up	72	520
2:34	MCE	10-15-74-U	47	116	Inlet Up	63	540
2:34	PVC	10-15-75 Pr	47	137	**Personal**	110	770
2:34	PVC	10-15-76 P	47	138	Inlet Dn	84	610
2:34	PVC	10-15-77 P	47	136	Inlet Dn	75	550

Table 2. Concentrations of airborne inhalable granite dust.

breaks/talking, cleanup, etc., do not place workers in direct plumes of dust. Due to the ambient dust load in the shop, often a visible cloud, some exposure also takes place during the other tasks, but at a much lower concentration than during the cutting, grinding, and polishing. As a reasonable estimate it is assumed that the dust sampling performed applies to 70% of the work day for the fabricators.

All of the airborne dust results are above the TLV (ACGIH) for inhalable dust of 10 mg/m^3. Many of the results are more than a factor of ten (10) above the TLV. Even wearing a half-face mask, with a protection factor of ten, would not provide adequate protection. Furthermore; application of a protection factor of ten for respirators would basically require a Respiratory Protection Program and proper fit testing.

The “Time-Weighted-Average” (TWA) for the six personal sample results is 525 mg/m³ for a sampling period of 2.55 hours. A normal fabrication-working shift, based on the previously denoted time study is 5.6 hours (i.e., 8 hrs x 70%). The shortened shift for the field test was due to the efforts of extensive sampling and organization for the field study. Based on the 70% work-shift the 8-hr TWA is 144 mg/m³ (525 mg/m³/ (2.55/5.6)/8 hours). This 8-hr TWA is more than 10 times the TLV. An independent investigator provided preliminary results for one granite shop indicating similar 8-hr TWA values, providing supplemental information supporting this field study.

Potential Crystalline Silica Exposures and Impact

Table 3 provides the results for crystalline silica monitoring for both respirable dust samples and personal inhalable dust samples. Results are given for both dry and wet operations. All of the crystalline silica results for respirable dust are above the TLV (ACGIH) of 0.025 mg/m^3 for respirable crystalline silica. These crystalline silica results for respirable dust are more than a factor of ten (10) above the TLV. The respirable dust values range from 60 to several hundred times the TLV.

Process	Sample ID	Sample Type	Crystalline Silica mg/sample	mg/m^3
Dry Grinding	10-15-19-R	Respirable	0.067	1.5
Dry Cutting	10-15-38-R	Respirable	0.6	5.8
Dry Cutting	10-15-58-R	Respirable	20%	11
Wet Cutting	10-15-8-R	Respirable	3.8 * 20%	0.8*
Wet Cutting	10-15-9-R	Respirable	1.8 * 20%	0.4*
Wet Grinding	10-15-28-R	Respirable	2.3 *20%	0.5*
Wet Grinding	10-15-25-Pers	Personal	0.37	3.4
TWA-8hr,70% Work Time, Dry Work, Personal**			**144 * 20%**	**29**

Table 3. Concentrations of inhalable crystalline silica.
* Crystalline silica was calculated at 20% of total dust on filter. Actual value may be greater.
** Time Weighed Average (TWA) for the personal samples is given in the next section.

The value for the Personal sample and the TWA (Time Weighted Average) for Personal samples are also much more than a factor of ten (10) above the PEL for inhalable dust. The TWA value for Personal Samples, at the bottom of the table is taken from the results in the next section. It is based on personal inhalable dust samples taken over an 8-hr work shift, and is based on a time study showing about 70% of work in the high dust areas during the shift. This value is several hundred times the Cal/OSHA PEL for inhalable dust.

Even wearing a half-face respirator, with a protection factor of ten, exposure would still exceed the TLV. It should be noted that these data represent exposures during both wet fabrication and dry fabrication. Although exposures are considerably greater during dry fabrication, exposures during wet fabrication still exceed the TLV by an order of magnitude.

It should be noted that the two samples 10-15-8-R and 10-15-9-R were collected at the beginning of the work shift. Therefore, those samples did not include airborne dust from processes earlier in the day. Any airborne material collected in those samples was due to the wet cutting process or suspended fine particulate remaining from the previous day.

Potential Radiation Exposures from Inhalable Dust

Table 4 provides the results for uranium and thorium concentrations in airborne dust for nine (samples) and the concentration based on the previously calculated TWA for airborne dust. Uranium and thorium analyses were only performed on samples when there was sufficient dust to ensure results above the analytical "Reporting Limit" (RL). The lab mistakenly disposed of or damaged three of the personal samples prior to analysis for uranium and thorium, leaving only three of the personal samples for uranium and thorium analysis.

The first six samples in Table 4 are from the fabrication of the vanity top using the Four Seasons granite. The dust results for these samples were given in Table 2 along with additional data on the sampling. The first four digits of the sample number (e.g., 10-15 for the date) are deleted to expedite formatting the table. The TWA for the personal samples is given in the seventh row of the table (bolded to high light it). Three additional samples are given at the bottom from fabrication of more elevated sections of granite.

The concentrations of uranium and thorium are given in the two columns on the right of the table. The variations in the top six samples, all from the same section of granite (Four Seasons Bordueux), are due to variations in the uranium and thorium in the section of granite being worked, and analytical and sampling variabilities. These types of variations are what are normally expected. The average uranium concentration (about 10 pCi/g) is about ten times that of normal soil (NCRP 2009) and represents relatively low to mid-level granite. The average thorium concentration, about 2 pCi/g, is about twice that of normal soil (NCRP 2009).

The uranium and thorium concentrations as mg/m³ are given in Table 4 to support the subsequent assessments provided in Table 5 and allow comparison to the uranium TLV. The only value above the uranium TLV of 0.2 mg/m³ is for the result at the bottom of the table. The inadequacy of using the TLV is illustrated by the radiation exposure results in Table 5.

The potential radiation doses from exposure to airborne inhalable dust from fabrication are given in Table 5. Doses are given for all of the sample results provided in Table 4. The sample numbers are the same as for Tables 2 and Table 4 Results are given for the concentrations of uranium and thorium in uCi/cc (microcuries per cubic centimeter; where a uCi is one millionth of a Curie), the units for DACs in radiation regulations (e.g., 10 CFR 20, NRC 2011). Two sets of radiation doses are given, one for the updated ICRP Publication 68 (ICRP 1994) dosimetry and on the far right for the NRC regulatory base dosimetry (NRC 2011, EPA 1988). The doses are given as annual doses, based on an occupational breathing rate of 1.2 m³/hr (NRC 2011) and an occupational year of 1400 hours (70% of 2000-hr year).

Time	**Sample ID**	**Time Min**	**Type Sample**	**Ave Dust Mg/m³**	**U mg/m³**	**Th mg/m³**	**U pCi/g**	**Th pCi/g**
9:47	11/14 U	46	Inlet Up	238	0.0087	0.0038	12.1	1.7
11:14	31/32 U	76	Inlet Up	185	0.0042	0.0021	7.5	1.2
11:14	35 Per	16	Personal	1800	0.130	0.059	23.3	3.5
11:30	45 Per	22	Personal	250	0.0036	<0.016	4.8	< RL
2:34	73/74 U	94	Inlet Up	68	0.019	0.0058	11.6	1.2

2:34	75 Per	47	Personal	770	0.036	0.017	15.2	2.4
TWA Personal, 2.55 hr sampling				**525**	**0.023**	**0.014**	**14.4**	**3.0**
Run 10/15 Section of elevated Bordueux, dust oriented towards sampler								
8:35	01/02 U	30	Inlet Up	1248	0.12	0.077	28.1	5.7
Run 10/15 Section of elevated Bordueux								
9:23	12/14 U	84	Inlet Up	1337	0.054	0.027	13.4	2.2
Run 10/15 Elevated sections of granite, Four Seasons and Niagara Gold								
11:03	33/34 U	174	Inlet Up	2338	0.23	0.12	33.7	5.6

Table 4. U & Th concentrations in granite fabrication dust.

The focus of the assessment in this section is on the updated ICRP Publication 68 dosimetry, the preferred technical base, used by most nations, and recognized as valid by the NRC (NRC 1999). The columns denoted ICRP 68 are dose results for uranium, thorium, and the total of uranium and thorium, based on the specified default particle size for industrial work of 5 um EAD (ICRP 1994). The column on the far right provides the doses based on the NRC regulatory framework (NRC 2011) using dose factors from Federal Guidance Report 11 (EPA 1988), which requires a default particle size of 1 um EAD, without specific information to the contrary. Generally, the smaller the particle size the greater the uptake within the respiratory system and the higher the dose.

There is minimal information on the particle size of the airborne material from granite fabrication. Optical microscopic analysis of two samples from the earlier March 2009 scoping field study indicated a nominal particle size of 10 um EAD. This microscopic sizing was performed on dust from cassettes that were grossly overloaded, containing about 150 mg of material. The samples had been stored for about six months prior to the analysis. It's perceived that conglomerates could have formed in the loaded dust, and there is hence uncertainty in the results. Limited sampling by an independent investigator provided preliminary results for one facility, using an 8-stage Anderson Impactor, with a pre-cut point of 20 um, indicated an EAD of about 3.5 um. Given the use of the 20-um pre-cut, the actual airborne particle size would be larger, possibly around 5 um EAD. Based on these limited data and the uncertainties, a reasonable conservative estimate is a particle size distribution of about 5 um EAD, the ICRP Publication 68 default value (ICRP 1994).

Sample ID	**Type Sample**	**U uCi/cc**	**Th uCi/cc**	**ICRP 68 U rem/yr**	**ICRP 68 Th rem/yr**	**ICRP 68 Total Dose Rem/yr**	**NRC Base rem/yr**
11/14 U	Inlet Up	2.9E-12	4.1E-13	0.87	0.14	1.01	4.21
31/32 U	Inlet Up	1.4E-12	2.3E-13	0.42	0.07	0.50	2.11
35 Per	Personal	4.3E-11	6.4E-12	13.1	2.11	4.71	63.5
45 Per	Personal	1.2E-12	1.9E-13	0.36	0.06	0.65	1.78

73/74 U	Inlet Up	6.3E-12	6.3E-13	1.91	0.21	2.12	8.51
75 Per	Personal	1.2E-11	1.9E-12	3.62	0.61	3.08	17.8
TWA Personal		**7.6E-12**	**1.6E-13**	**2.28**	**0.51**	**2.79**	**12.2**
Run 10/15 Section of elevated Bordueux, dust oriented towards sampler							
01/02 U	Inlet Up	4.0E-11	8.4E-12	12.1	2.75	14.82	64.8
Run 10/15 Section of elevated Bordueux							
12/14 U	Inlet Up	1.8E-11	2.9E-12	5.43	0.96	6.39	27.1
Run 10/15 Elevated sections of granite, Four Seasons and Niagara Gold							
33/34 U	Inlet Up	7.7E-11	1.3E-11	23.1	4.29	27.4	117

Table 5. U & Th potential radiation doses airborne dust from fabrication.

The results in Table 5 or the fabrication of the vanity top (upper six values in the table) indicate potential doses of 0.5 to 4.7 rem/yr (70% of 2000-hr year). The results for the three personal samples are similar to those for the area samples. The best estimate is the TWA based value of 2.8 rem/yr. The potential exposures, based on the TWA are about 28 times the exposure criterion of 0.1 rem/yr. The assessment approach was to provide reasonable estimates, with limited conservatism for uncertainties. The three results at the bottom of the table, for more conservative assessment of working conditions and materials, indicate higher radiation doses.

The dose estimates using the dosimetry for the present U.S. framework of regulations provide much higher doses, largely because of the older dosimetry system from ICRP 30 and the use of a default particle size of 1 um EAD (EPA 1988, ICRP 1979). The TWA related dose estimate is 12 rem/year, more than twice even the occupation regulatory limit of 5 rem/yr (NRC 2011), and more importantly over 100 times the proper criterion of 0.1 rem/yr. Modifying this dose to relate to a particle size distribution of 5 um EAD, only reduces the estimate to about 8 rem (Eckerman 2011), still 80 times the applicable criterion.

As has been emphasized, there is only minimal data on the appropriate particle size distribution. It is perceived that the focus on a distribution of 5 um EAD is reasonable, but possibly conservative. If a 10 um EAD particle size distribution is applicable, the ICRP 68 based dose estimates would only be reduced by about 40 percent; that is the TWA-based estimate would be about 1.6 rem/yr, still grossly above the acceptable criterion. The NRC dosimetry based estimate would be about 70% of the values in Table 5.

Assessments have been performed for worker exposures due to inadvertent ingestion of dust due to poor hygiene procedures (e.g., dirty hands and smoking in the work area) and external gamma exposure due to work with the granite (Bernhardt 2009). Working with granite similar to that used in this field study (10 pCi/g of uranium-238) results in potential doses of about 0.01 rem/year. Work with more elevated granite can result in doses of about 0.05 rem/year (Bernhardt 2009).

Summary and Conclusions

Perfection is difficult to obtain, but there is an immense opportunity for improving the working conditions in small granite fabrication shops. There are claims that large shops have better work conditions due to more sophisticated dust control and tools for more extensive wet fabrication. But, the verification of this is minimal. Our primary concern is to convey information to workers and improve the work conditions in all shops.

The following items briefly summarize potential exposures as identified by the field study and related assessments:

- The TWA for personal samples is 144 mg/m^3 inhalable dust, based on 8-hr TWA and a 70% time of exposure, compared to the ACGIH TLV (ACGIH 2011) of 10 mg/m^3.
- Concentrations of crystalline silica in respirable dust ranged from 1.5 mg/m^3 to 11 mg/m^3 for dry fabrication operations and 0.5 mg/m^3 to 0.8 mg/m^3 for wet operations, with all results exceeding the ACGIH TLV of 0.025 mg/m^3 by more than a factor of ten (10).
- Concentrations of crystalline silica in respirable dust for dry operations all exceeded the TLV by a factor of 60 to hundreds.
- The TWA-8hr average for crystalline silica, derived from personal samples (inhalable dust) was 29 mg/m^3, several hundred times the Cal/OSHA PEL (inhalable dust) of 0.1 mg/m^3.
- The TWA based radiation exposure for personal air samples, using the updated ICRP dosimetry is 2.8 rem/yr, compared to the guidance criterion of 0.1 rem/yr. The dose estimates for the present NRC regulatory framework (older dosimetry) are 12 rem, over 100 times the exposure criterion.

The following suggested desired actions and improvements in the operations of granite fabrication are not listed in the order of priority nor is the list exhaustive, However, the first item, based on workers being properly informed, is the top priority. Informing and training workers and shop owners will bring about improvements and make implementing other improvements easier. Implementing these improvements may not reduce exposures sufficiently to meet desired health protective conditions and appropriate criteria, but they will produce significant reduction of exposures and risks—not perfection, but improvement.

- Inform and train shop owners and workers.

- No smoking, eating, or drinking from open containers in work area, and provide hand washing facilities.

- Respiratory Protection Program, half-face respirators or supplied-air air hats, training on use, and fit tests. Air hats provide more protection than half-face respirators.

- Improve shop ventilation and dust control.

- Optimize fabrication techniques; maximize wet techniques to minimize dust production.

- Wear shop clothing, don't take dusty clothing home (results in exposure of family members).

- Screen granite to exclude granite with high concentrations of uranium and thorium. Some shops use a screening level of about 20 uR/hr above background.

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