Background Beryllium

Statistical tools for using bulk samples to assess building contamination

By Robert A. Brounstein

BERYLLIUM HEALTH HAZARDS were first observed in the 1940s when a cluster of cases within the fluorescent light industry were associated with chronic beryllium disease (CBD) (Kolanz, 2001). CBD is a granulomous lung disease that can be debilitating and sometimes fatal (Henneberger, Goe, Miller et al., 2001). While beryllium has properties that are advantageous for several industries, its uniqueness for the nuclear industry that made it a necessary component for fuel rods, reflectors, moderators (controlling neutron migration) and neutron sources (Fields, 2001).

Because this type of work in the U.S. was and is associated with Department of Energy (DOE), workers within the DOE community and the former Atomic Energy Commission have been a major exposure group (Henneberger et al., 2001). Current studies have indicated that since the 1940s, more than 26,000 people have worked with beryllium at DOE facilities, with an additional 8,100 workers who currently work in such environments. The total number of employees being placed on medical surveillance as a result of potential beryllium-associated work is expected to grow to 40,000 within a few years (Henneberger et al.).

In 1999, the DOE promulgated the Chronic Beryllium Disease Prevention Program (CBDPP), which is published as 10 CFR Part 850. This standard applies to DOE offices and contractors. While reinforcing the 2.0 $\mu g/m^3$ permissible exposure limit (PEL) established by OSHA (2004) in 29 CFR 1910.1000, an action level of 0.2 $\mu g/m^3$ was added (DOE, 1999).

Along with these exposure limits for inhalation, surface criteria were added. According to this standard, areas where beryllium operations occur need to have surfaces cleaned to 3 $\mu g/100\ cm^2$ excluding enclosed spaces, such as ventilation systems and glove bags. Equipment and materials being removed from a site need to comply with the 10 CFR Part 850 release criteria: 3 $\mu g/100\ cm^2$ for release to other DOE beryllium facilities or 0.2 $\mu g/100\ cm^2$ if being transferred to a nonberyllium or public location (DOE, 1999).

To supplement the CBDPP, DOE (2001) published an implementation guide to help line managers meet their responsibilities under the program. According to the guide, housekeeping requirements as detailed in 10 CFR Part 850.30 are intended to ensure that beryllium areas are cleaned to a specific level: 3.0 $\mu g/100\ cm^2$. This housekeeping criterion is used to identify area sources of airborne beryllium and to ensure that airborne beryllium emissions are under control (DOE, 1999).

In 10 CFR Part 850.31, DOE's release criteria, the agency suggests that background soils may interfere or influence the determination of whether equipment and materials from a beryllium-identified location are truly contaminated. Thus, DOE (1999) requires the responsible employer to ensure that:

> The removable contamination level of equipment or item surfaces does not exceed the higher of 0.2 $\mu g/100\ cm^2$ or the concentration level of beryllium in soil at the point or release, whichever is greater.

The implementation guide goes a step further, acknowledging that when background beryllium soils are present, they should be considered and that they may contribute to beryllium surface levels exceeding the release limits.

> Because beryllium is ubiquitous throughout the U.S., background soil accumulation on a surface in a DOE/NNSA facility could contain more beryllium than the release criteria of 0.2 $\mu g/100\ cm^2$ for public or nonberyllium use (DOE, 2001).

Today, many facilities within the DOE community are slated for decontamination and decommissioning (D&D). As part of the D&D process, these facil-

Robert A. Brounstein, M.S., CSP, CIH, *is a program industrial hygienist for Washington Closure-Hanford at the Hanford Department of Energy (DOE) site in Richland, WA. He is currently involved in a major remediation project involving clean-up of buried waste sites, and decommissioning and demolition activities where plutonium production was the primary mission during the World War II and Cold War eras. Brounstein holds a B.S. in Chemical Engineering from California State Polytechnic University and an M.S. in Health Physics from the University of Nevada-Las Vegas. He is a professional member of ASSE's Lower Columbia Basin Chapter.*

Abstract: *Since the Department of Energy (DOE) published its Chronic Beryllium Disease Prevention Program in 1999, SH&E professionals have faced the dilemma of understanding whether beryllium on surfaces is due to beryllium operations or to an accumulation of background soils. Background soils could contribute significantly to detectable beryllium within facilities since beryllium is naturally occurring. SH&E professionals must determine how to quantify and segregate background beryllium from beryllium due to current or past operations. This article discusses this complex task, as well as tools for assessing whether a beryllium health concern exists in a facility.*

ities must undergo remediation and decontaminating prior to demolition. This requires that workers be protected from hazards, many of which are chemical and, therefore, pose a health risk due to inhalation (as well as through skin, eyes and ingestion). Because beryllium has been a major concern at many DOE facilities (DOE, 1999), worker concerns about contracting CBD must be addressed.

10 CFR Part 850 specifies many requirements to protect workers. These include:

- written CBDPP;
- medical screening;
- training;
- PPE;
- respiratory protection (and qualification);
- decontamination;
- sampling/monitoring;
- postings.

Implementing these requirements demands significant company resources, including medical personnel (for surveillance), increased staffing (to implement the CBDPP), equipment and materials, and training and education. These requirements are designed to ensure that the workforce understands the health effects associated with beryllium exposure, including the various controls for proper protection. Employers must also provide information regarding specific beryllium-related work tasks and train employees what to do if they feel their health may be compromised due to performing such tasks. Considering the number of people potentially exposed to beryllium at DOE facilities (up to 40,000), implementing 10 CFR Part 850 carries significant costs.

Part of the D&D process involves vacating a facility, whereby entry is restricted to periodic inspections and the maintenance of critical structures such as roofs, electrical and fire protection systems (DOE, 1998). The facility remains in this condition until it is ready for decontamination and/or dismantlement. This period of limited surveillance and maintenance may continue for extended periods and may last for years (DOE, 1998).

During this time, no janitorial and other types of cleaning services are performed. As a result, debris, including soils that have migrated due to windy conditions (James & Croissant, 1994), could enter into these facilities, causing accumulation of native materials such as soils (see Photos 1-4 on p. 37). Ventilation systems, ducts, unsealed openings and foot traffic dragging in outside soils are viable pathways for soils to enter buildings. Openings and cracks in ceilings may also contribute to soil migration into facilities, with the soil accumulating on floors, mezzanines, equipment and table surfaces.

According to Section 4.2.2.1 of the implementation guide, beryllium from soils has not been identified as being related to causing adverse health affects (DOE, 2001). Therefore, if it can be determined that the beryllium detected during laboratory analysis is not associated with a beryllium process, but instead is due to naturally occurring beryllium (from soil accumulation), a beryllium exposure health hazard may not be present.

According to the U.S. Geological Survey, as a naturally occurring element, beryllium is found in soils throughout the U.S., ranging from 0.3 mg/kg to 15 mg/kg, with a geometric mean of 0.68 mg/kg (Shacklette & Boerngen, 1981). So while organizations may sample for possible beryllium contamination using surface wipe methods and if soil accumulation is visible, it would be logical to expect to detect a certain amount of beryllium. Just how much of this beryllium is attributable to background conditions and how to assess this influence is the focus of this article.

While implementing a CBDPP is necessary when beryllium is identified, erring on the conservative side and establishing a program when it is not necessary can have severe consequences. Such situations can lead to extreme and unnecessary costs for program implementation while causing the workforce unwarranted concerns and/or anxiety.

This article explores the use of two statistical tools: upper tolerance limit (UTL) and the *Multi-Agency Radiation Surveys and Site Investigation Manual* (MARSSIM). Both can help SH&E professionals determine the influence of naturally occurring background beryllium and, thus, enable practitioners to exercise proper professional judgment and take an appropriate path forward to protect the workforce.

Identifying surface contamination levels as indistinguishable from background conditions is by no means a breech of ethics. Acknowledging that beryllium in soils is a naturally occurring phenomenon and that a viable migratory path exists by which background conditions influence indoor environments to the point that the health and well being of the workers is not compromised is a useful and prudent cause to promote. Therefore, the decisions of SH&E professionals can protect both employee and employer while resulting in cost-effective benefits.

Comparing Apples to Apples

Without determining background soil conditions, it is strongly possible that many facilities and locations may be subject to a high accumulation of surface debris which originated from natural background conditions, rather than current/past activities. Therefore, employing the 100 cm^2 wipe sampling method specified in 10 CFR Part 850 (DOE, 1999) may result in the collection of large amounts of dirt and debris strictly based on months or years of accumulation of background material, not because of any type of beryllium operation. As a result, unwarranted time, effort and money could be exhausted for decontamination when it is not necessary.

Therefore, it is necessary to identify alternative methods for determining whether beryllium is due to background soil conditions or truly the result of past/present operations. A logical approach would be to first determine background beryllium soil concentrations. Once this is known, an employer can compare these concentrations to beryllium surface levels within a facility.

However, since DOE housekeeping and release criteria are expressed in mass per unit area, while

Photos 1-4: During the D&D process, a facility is vacated and entry is restricted to periodic inspections and the maintenance of critical structures. Since no janitorial or other types of cleaning services are performed during this time, debris, including soils that have migrated due to windy conditions, could enter into these facilities.

the background soil concentrations are expressed in mass of beryllium per mass of soil, a method is needed by which surface conditions can be compared to background soil conditions. Without this, no comparison can be achieved.

One way to achieve this comparison is to collect surface material within facilities of concern. In this process, instead of traditional surface wipe sampling, the surface material is collected as bulk media. This would allow the analytical laboratory to provide results in terms of concentration as mg/kg—the same units used to express beryllium soil concentrations.

The next step to consider is how to achieve a comparison between beryllium from facility surfaces and background soil based on a convincing level of confidence. This requires the use of statistical tools with the objectives being to determine 1) what appropriate soil concentration is to be used as a comparison for facility surfaces; 2) how many samples should be collected inside the facility; and 3) where to sample inside a facility.

Using UTL

Background beryllium soil concentration can be calculated through methods described in *A Strategy for Assessing and Managing Occupational Exposure* (Mulhausen & Damiano, 1998). This book explains the purpose of collecting enough data so that tolerance limits can be established. Tolerance limits, while having a similar statistical approach as confidence limits, are slightly different in that all the data collected may fall within a 95% tolerance limit, while, by definition, confidence limits will produce outlying points from the collected data.

For example, suppose 20 soil samples were collected for beryllium analysis and the results indicated a beryllium soil concentration range from 0.9 mg/kg to 1.5 mg/kg. Depending on the standard deviation, a calculated 95% upper confidence limit, based on a normal distribution, could most likely result in a concentration lower than the high soil concentration of 1.5 mg/kg. Therefore, the soil concentration of 1.5 mg/kg would be considered as an outlier (while including the other soil concentrations from the remaining 19 samples), even though the soil concentration of 1.5 mg/kg was obtained from native soils.

However, in the case of UTLs, depending on the standard deviation, a 95% UTL could very well encompass all the beryllium soil samples, including the highest sample value. Therefore, all soil data collected would be considered as falling within the accepted range of the 95% upper tolerance beryllium soil concentration. This means that samples with a beryllium concentration greater than the 95% UTL would then be considered suspect; one, therefore, could not state that the surface materials in the facility were within the 95% UTL.

However, if all the samples collected in a facility were within the 95% UTL, it could be stated that surface materials in that specific facility were within the 95% UTL and, therefore, the facility surface materials have a beryllium concentration which is indistinguishable from background beryllium conditions. As a result, the facility would not be considered beryllium-contaminated.

UTL is calculated using the following formula:

UTL = X + ks
where X = average concentration (mg/kg)
s = standard deviation
k = specific constant based on the required tolerance

The k value is based on the function of confidence (probability), percentile and number of samples (Dixon & Massey, 1969). In other words, tolerance limits are endpoints of specific intervals that cover a fixed proportion of a population or sample group with a stated confidence. Therefore, one can say with 95% confidence that 95% of all samples collected will be within the specified population or sample group and is expressed as a 95%, 95% UTL or $UTL_{95\%,95\%}$. This is based on a normal distribution whereby the constant "k," used for a 95% tolerance limit that is based on a 95% confidence, is a very large number for small sample sizes (e.g., 37.674 for a sample size of 2 data points) while decreasing to finally approaching 1.96 (the constant for a 95% confidence limit) as the sample sizes increase and approach infinity (Dixon & Massey, 1969).

Collecting Background Samples

Before establishing the $UTL_{95\%,95\%}$, the number of

Table 1

Values of P_r for Given Values of the Relative Shift, Δ/σ, when the Contaminant Is Present in Background

Δ/σ	P_r	Δ/σ	P_r
0.1	0.528182	1.4	0.838864
0.2	0.556223	1.5	0.855541
0.3	0.583985	1.6	0.871014
0.4	0.611335	1.7	0.885299
0.5	0.638143	1.8	0.898420
0.6	0.664290	1.9	0.910413
0.7	0.689665	2.0	0.921319
0.8	0.714167	2.25	0.944167
0.9	0.737710	2.5	0.961428
1.0	0.760217	2.75	0.974067
1.1	0.781627	3.0	0.983039
1.2	0.801892	3.5	0.993329
1.3	0.820978	4.0	0.997658

If $\Delta/\sigma > 4.0$, use $P_r = 1.000000$

Note. *Reprinted from* Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Revision 1 *(Table 5.1, p. 5-28), by U.S. Department of Energy (DOE), 2000, Washington, DC: Author.*

background samples must be determined. EPA (1992) has established a sampling method for soils in *Preparation of Soil Sampling Protocols: Sampling Techniques and Strategies*. This publication describes various methods, including equipment and design strategies. One of the simplest methods (and useful for establishing ground beryllium soil concentrations) incorporates what EPA refers to as *systematic sampling*. Using this method, soil is collected in a regular pattern, such as a grid or line transect, over an area of interest.

To establish background soil information near/around a specific building, samples must be collected within the location of the closest native soils. According to EPA (1992), the spacing of soil samples must be close enough to provide a measure of the continuity of the location-to-location variation within a soil sampling unit. This can be accomplished by designing a grid pattern similar to the one intended to be incorporated inside the facility of concern.

One can establish a soil sampling grid pattern based on the directions used in a typical rose wind pattern: north, south, east, west, northeast, northwest, southeast and southwest. It is recommended that more than one sample be collected from each direction while sampling in varying distances for each direction. For example, soil collection from the north could involve 2 samples collected at distances of 10, 25 and 50 ft from the facility of concern. This would result in 48 total samples. A minimum of 20 total background samples need to be collected to achieve a $UTL_{95\%,95\%}$ (Mulhausen & Damiano, 1998).

Because top soils are the materials most likely to migrate due to winds (James & Croissant, 1994), soil samples should be collected within the upper soil layer. EPA (1992) divides soil sampling into two categories: 1) the upper 6 in. and 2) the upper 3 ft. The upper 6 in. sampling is designed to capture contaminants caused by recent spills or insoluble chemicals, while the upper 3 ft level is for more soluble materials or materials deposited years prior to sampling. Therefore, because beryllium and its compounds are solid and considered insoluble (NIOSH, 2004), collection from the upper 6 in. is the more appropriate scenario.

EPA (1992) also lists several types of sampling equipment. For surface sampling, examples include soil punches (thin-walled tubes, approximately 6 to 8 in. long, designed to be pushed into the soil), scoops or shovels. Because a large soil volume is not necessary (as the analytical laboratory needs amounts much smaller than what a soil punch can provide), using a scoop or trowel is likely the best approach (EPA, 1992). However, one should contact the analytical laboratory that will handle the sampling to discuss the most appropriate collection method and optimum quantity.

Once collected, samples need to be sent for analysis. This analysis must be conducted by the same analytical laboratory using the same analytical method that will be employed for all samples collected during the entire assessment process.

Once analysis has been completed, $UTL_{95\%,95\%}$ can be calculated. This concentration will be used to establish the background beryllium concentration at which any reading below this level cannot be distinguished from background conditions and, therefore, should not be considered as an indication for beryllium contamination.

The MARSSIM Approach

Once $UTL_{95\%,95\%}$ has been established, a sampling strategy should be employed so that a sufficient number of samples are collected to provide statistically defensible evidence. Such a strategy can be developed by using the MARSSIM.

MARSSIM is a 4-year collaborative effort of a multi-agency workgroup consisting of the departments of Defense and Energy, EPA and Nuclear Regulatory Commission; many other individuals and organizations contributed to its development as well (DOE, 2000). This document offers detailed guidance for planning, implementing and evaluating environmental and facility radiological surveys conducted to demonstrate compliance with a dose- or risk-based regulation. While the document is designed for use in investigating radiological contamination, many of the concepts can be applied within the field of industrial hygiene. These concepts offer the SH&E community some valuable strategies that can be used to determine whether surface contaminants (such as beryllium) can be appropriately assessed.

After establishing background concentrations, the facility must be divided into manageable sampling areas or survey units. MARSSIM defines a survey unit as a physical area consisting of structures or land areas of specified size and shape for which a separate decision will be made regarding whether that area exceeds the release criterion (DOE, 2000). Thus, the survey unit is the basic division within the facility for sampling and contaminant identification.

MARSSIM categorizes survey units into three classes, each of which can be further characterized as either a land area or structure. These classifications and their corresponding suggested size are as follows:

- Class 1 structure: up to 100 m^2 floor area;
- Class 1 land area: up to 2,000 m^2;
- Class 2 structure: from 100 to 1,000 m^2;
- Class 2 land area: from 2,000 to 10,000 m^2;
- Class 3 structure: no limit;
- Class 3 land area: no limit.

The classes are defined as:

- Class 1: areas that have or had prior to remediation a potential for contamination.
- Class 2: areas that have or had prior to remediation a potential for contamination, but not to exceed the UTL.
- Class 3: any impacted areas that are not expected to contain any residual contamination or are expected to contain small fractions of the contaminant based on operating history and previous surveys (DOE, 2000).

Table 2

Table 2

Percentiles Represented by Selected Values of α and β

α (or ß)	$Z_{1-\alpha}$ (or $Z_{1-\beta}$)	α (or β)	$Z_{1-\alpha}$ (or $Z_{1-\beta}$)
0.005	2.576	0.10	1.282
0.01	2.326	0.15	1.036
0.015	2.241	0.20	0.842
0.025	1.960	0.25	0.674
0.05	1.645	0.30	0.524

Note. *Reprinted from* Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Revision 1 *(Table 5.2, p. 5-28), by U.S. Department of Energy (DOE), 2000, Washington, DC: Author.*

The actual survey unit size is only a suggestion, meaning users may develop their own survey unit size to fit specific needs or requirements (DOE, 2000).

Once the number of survey units has been established, the number of samples in each unit needs to be calculated. This requires using two parameters: 1) the derived concentration guideline level (DCGL) and 2) the lower bound of the grey region (LBGR). DCGL is a radionuclide-specific surface or volume residual radioactivity level that is related to a concentration or dose or risk criterion (DOE, 2000). While the regulator (e.g., DOE, NRC) usually determines this criterion, for this purpose, DCGL has already been determined through the calculated $UTL_{95\%,\ 95\%}$, which is the contamination criterion.

LBGR is a concentration that is less than DCGL; it is chosen to be easily distinguishable from DCGL and can be considered to be the average beryllium-soil concentration. According to MARSSIM, a statistical test may be used to determine whether the true concentration in the survey unit is above DCGL or below LBGR (DOE, 2000). However, one is more likely to make an inaccurate decision if the true concentration of the survey unit is between these two parameters. Thus, the area between DCGL and LBGR is called the "grey region," meaning the decision is usually considered neither black nor white (DOE, 2000).

It is important that LBGR represents a concentration which when reported via analysis leaves little doubt that the detectable beryllium concentration is attributed to background—or at least is indistinguishable from background. Therefore, LBGR can be considered to be the average soil concentration (obtained during the background soil collection and analysis).

Another important term is relative shift, which is the difference between DCGL and LBGR, divided by the standard deviation. Mathematically, the relative shift can be expressed as Equation 1:

Table 3

Values of N/2 for Use with the Wilcoxon Rank Sum Test

	α=0.01					α=0.025					α=0.05					α=0.10					α=0.25				
	β					β					β					β					β				
Δ/σ	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25	0.01	0.025	0.05	0.10	0.25
0.1	5452	4627	3972	3278	2268	4627	3870	3273	2646	1748	3972	3273	2726	2157	1355	3278	2646	2157	1655	964	2268	1748	1355	964	459
0.2	1370	1163	998	824	570	1163	973	823	665	440	998	823	685	542	341	824	665	542	416	243	570	440	341	243	116
0.3	614	521	448	370	256	521	436	369	298	197	448	369	307	243	153	370	298	243	187	109	256	197	153	109	52
0.4	350	297	255	211	146	297	248	210	170	112	255	210	175	139	87	211	170	139	106	62	146	112	87	62	30
0.5	227	193	166	137	95	193	162	137	111	73	166	137	114	90	57	137	111	90	69	41	95	73	57	41	20
0.6	161	137	117	97	67	137	114	97	78	52	117	97	81	64	40	97	78	64	49	29	67	52	40	29	14
0.7	121	103	88	73	51	103	86	73	59	39	88	73	61	48	30	73	59	48	37	22	51	39	30	22	11
0.8	95	81	69	57	40	81	68	57	46	31	69	57	48	38	24	57	46	38	29	17	40	31	24	17	8
0.9	77	66	56	47	32	66	55	46	38	25	56	46	39	31	20	47	38	31	24	14	32	25	20	14	7
1.0	64	55	47	39	27	55	46	39	32	21	47	39	32	26	16	39	32	26	20	12	27	21	16	12	6
1.1	55	47	40	33	23	47	39	33	27	18	40	33	28	22	14	33	27	22	17	10	23	18	14	10	5
1.2	48	41	35	29	20	41	34	29	24	16	35	29	24	19	12	29	24	19	15	9	20	16	12	9	4
1.3	43	36	31	26	18	36	30	26	21	14	31	26	22	17	11	26	21	17	13	8	18	14	11	8	4
1.4	38	32	28	23	16	32	27	23	19	13	28	23	19	15	10	23	19	15	12	7	16	13	10	7	4
1.5	35	30	25	21	15	30	25	21	17	11	25	21	18	14	9	21	17	14	11	7	15	11	9	7	3
1.6	32	27	23	19	14	27	23	19	16	11	23	19	16	13	8	19	16	13	10	6	14	11	8	6	3
1.7	30	25	22	18	13	25	21	18	15	10	22	18	15	12	8	18	15	12	9	6	13	10	8	6	3
1.8	28	24	20	17	12	24	20	17	14	9	20	17	14	11	7	17	14	11	9	5	12	9	7	5	3
1.9	26	22	19	16	11	22	19	16	13	9	19	16	13	11	7	16	13	11	8	5	11	9	7	5	3
2.0	25	21	18	15	11	21	18	15	12	8	18	15	13	10	7	15	12	10	8	5	11	8	7	5	3
2.25	22	19	16	14	10	19	16	14	11	8	16	14	11	9	6	14	11	9	7	4	10	8	6	4	2
2.5	21	18	15	13	9	18	15	13	10	7	15	13	11	9	6	13	10	9	7	4	9	7	6	4	2
2.75	20	17	15	12	9	17	14	12	10	7	15	12	10	8	5	12	10	8	6	4	9	7	5	4	2
3.0	19	16	14	12	8	16	14	12	10	6	14	12	10	8	5	12	10	8	6	4	8	6	5	4	2
3.5	18	16	13	11	8	16	13	11	9	6	13	11	9	8	5	11	9	8	6	4	8	6	5	4	2
4.0	18	15	13	11	8	15	13	11	9	6	13	11	9	7	5	11	9	7	6	4	8	6	5	4	2

Note. *Reprinted from* Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) Revision 1 *(Table 5.3, p. 5-30), by U.S. Department of Energy (DOE), 2000, Washington, DC: Author.*

(DCGL - LBGR)/σ
where DCGL - LBGR = the shift
σ = the estimate of the standard deviation of the measured values within the survey unit

Because survey unit samples are pending at this time, MARSSIM states that σ can be an estimate value, based on site knowledge or by taking a limited amount of preliminary measurements (5 to 20 samples) (DOE, 2000). Because background conditions are an influence in facility surface conditions, using the σ from the collected soil data may be appropriate.

Once the surface data are collected, another calculation for σ (from the survey unit) can be conducted and compared to the original estimate. Based on this comparison, additional samples within the survey unit may be necessary because Equation 1 is used to obtain the specific number of samples. Thus, as σ changes, so will Equation 1; this in turn, will change other factors that are dependant on Equation 1.

Equation 1 can then be used to select the probability factor (P_r). P_r is the probability that a random measurement from the survey unit exceeds a random measurement from the background reference area by less than DGCL when the survey unit median is equal to LBGR. Therefore, P_r is the probability that a measurement within the survey unit may be within the grey region—that is, between the background average beryllium-soil concentration and the $UTL_{95\%,95\%}$.

An examination of Table 1 shows that as the relative shift increases, P_r trends toward unity. Thus, as the relative shift increases, which would be due to an increased shift (DGCL-LBGR) and/or a decreased relative shift (σ), there is an increased probability that a random sample in the survey unit will be within the boundaries of LBGR and DGCL (and, therefore, less than the $UTL_{95\%,95\%}$).

As an alternative to using this table, NUREG 1505 presents a formula by which P_r can be calculated (Gogolak, Powers & Huffert, 1998).

All this information helps answer the question, "How many samples should be collected for each survey unit?" To summarize, applying LBGR and DGCL (average soil concentration and the $UTL_{95\%,95\%}$, respectively) along with σ, P_r can be determined. This, in turn, is used to obtain the number of samples that must be collected from the survey unit, as illustrated in Equation 2 (DOE, 2000):

$N = (Z_{1-\alpha} + Z_{1-\beta})^2 / [3(P_r - 0.5)^2]$
where $Z_{1-\alpha}$ and $Z_{1-\beta}$ are decision error percentile values based on a normal distribution

As Table 2 illustrates, working within the 95% confidence criterion, both $Z_{1-\alpha}$ and $Z_{1-\beta}$ result in 1.645. (As one may realize, these values are the number of Z-values used in standard statistics to obtain one-sided 95% confidence limits based on type I and type II errors: the probability of obtaining a false positive or false negative error.)

Photo 5 (top left): A sampling methodology must be developed for the collection of bulk materials within survey units.

Photos 6 and 7 (top right and bottom left): Respiratory protection and other PPE may be required. In addition, since potential beryllium exposure is being assessed, persons conducting the sampling should wear personal sampling pumps.

Equation 2 now can be calculated. Because it is possible to miss or have unusable measurements (e.g., nondetect values and undetermined analyses), a level of uncertainty exists. Therefore, the number of data points (N) should be increased by 20% (DOE, 2000).

Next, N is divided by 2, which yields the number of sampling points within each survey unit (N/2), as well as in the reference/background area. In lieu of this calculation, MARSSIM includes a table whereby N/2 can be obtained (with the additional 20% data points) by knowing α and β (or using the desired α and β values) and the relative shift (DOE, 2000). Table 3 offers an easier approach that requires less mathematical calculation to obtain the number of necessary samples within a survey unit.

Because N/2 also represents the number of samples that need to be collected in the background area, the actual number of background samples collected must be compared to N/2. If N/2 is larger that the number of background samples, then additional background data are necessary. This would also require recalculation of the $UTL_{95\%,95\%}$ as well as all subsequent steps. However, if N/2 is less than the number of background samples, no further recalculations are necessary.

At this point, sampling locations can be easily mapped by using a sampling grid or floor plan of each survey unit (as-builts or architectural floor plans work well). The spacing for the samples is calculated as follows:

$L = \sqrt{A/N}$
Where:
A = the area of the survey unit;
N = the number of sampling points (calculated from the previous information);
L = the distance between each sampling point (based on the measurement unit of A).

The units must be consistent (e.g., feet, meters). Each survey unit should have a grid system that indicates the location for each sampling point. This can be accomplished by creating a standard Cartesian coordinate system, based on the size and configuration of the survey unit, and identifying the first sampling location at the position (0,0). Adjacent sampling points would then be designated L-feet/meters from this point. This mapping method would continue for determining all sampling points in the survey unit.

This sampling map would encompass elevated locations above 8 ft, as well as other locations not at floor surface, such as tables, cabinets and operating equipment. Therefore, sampling floor surfaces alone would not be appropriate. Section 4.2.1.4, Baseline Inventory Documentation, in DOE's (2001) implementation guide describes the various areas and types of equipment as well as floor surfaces that must be considered.

If necessary, the number of samples can be increased beyond N/2 so that all suspect surfaces can be sampled. However, as long as the minimum number of samples is collected for the locations/equipment of concern, survey unit results can be compared to the $UTL_{95\%,95\%}$ based on N/2 samples and, therefore, provide the necessary data to determine whether a survey unit has a beryllium surface concentration that is indistinguishable from background soils.

Sampling Survey Units

The next step is to develop an appropriate sampling methodology for the collection of bulk materials within the survey units. This can be accomplished using various techniques, including ASTM International's D7144-05a, Standard Practice for Collection of Surface Dust by Micro-Vacuum Sampling for Subsequent Metals Determination (ASTM, 2005). This method requires the use of either a matched-weight 37 mm diameter 0.8 micron pore mixed cellular ester fiber filter, or a preweighed PVC filter cassette connected to a sampling pump operating at 2.5 liters per minute (Photo 5).

According to the method, the filter should have a flexible plastic tubing extension from the filter inlet that functions as a collection nozzle. The nozzle should be placed close to the sampling surface, moving at a rate of 10 cm/s, repeating in a sweeping motion until enough material has been collected to completely cover the filter. While ASTM D7144 specifies a sampling area of 10 cm x 10 cm up to 25 cm x 25 cm, the actual sampling area is not as important as collecting enough material for the analytical laboratory to provide meaningful data.

For example, if an insufficient amount of material is collected, analysis may indicate nondetect concentrations at a limit greater than the background soil conditions. Obviously, this would not provide the information needed to determine the extent, if any, due to the influence of background soils. Therefore, it is important to contact the laboratory prior to sampling to determine the amount of material needed to receive acceptable data.

According the ASTM D7144-05a, this method has a bias toward collecting the lighter particle fractions. However, it is these lighter fractions that have a greater tendency to be carried via wind currents and, therefore, are the particles more likely to migrate from outside locations into building interiors through open doors, windows, ventilation systems, and damaged exterior walls and ceilings (ASTM, 2005).

Depending on the individual project requirements, industrial hygiene controls such as respiratory protection may be required (Photos 6 and 7, p. 41). In addition, since this sampling technique is designed to assess beryllium exposure potential, persons conducting the sampling should wear personal sampling pumps.

All samples, surface and personal, should be forwarded to an analytical laboratory accredited by AIHA. Typical analytical methods used are NIOSH 7300: inductively coupled plasma: atomic emissions spectroscopy; or NIOSH 7102: atomic adsorption: graphite furnace (NIOSH, 2003). Whichever method is used, it is important that only one lab conduct the analysis and that the selected method be used for the entire analytical process. In addition, it is not recommended that data sets from different analyses be compared.

The data for each survey unit can be compared to the background soil concentrations. Any surface bulk sample that has a recorded beryllium concentration greater than the beryllium-soil UTL would suggest that something other than background soils were contributing to beryllium surface contamination for a specific survey unit.

Therefore, any survey unit with even one bulk sample over the background beryllium soil concentration would need to be decontaminated, while any equipment and material leaving the area would need to meet mandatory release limits. This would apply only to those survey units above the $UTL_{95\%,95\%}$ background beryllium soil concentration, not the entire facility (DOE, 2000). Should every survey unit in a building indicate analytical results within the established $UTL_{95\%,95\%}$, the building can be considered to have surface materials with a beryllium concentration that is indistinguishable from the background soils; therefore, decontamination for beryllium would not be necessary.

Conclusion

The $UTL_{95\%,95\%}$ and MARSSIM sampling strategy can be used to determine whether beryllium is a potential concern in a facility. The results can be beneficial from both an SH&E perspective, as well as a cost-saving strategy, reducing time, equipment and materials release, and limiting compliance efforts when beryllium is not an exposure concern. However, the greatest benefit would be ensuring that occupational health has not been compromised.

Specific sampling methods for determining background conditions, as well as the various nuances involved with MARSSIM application require a more-detailed discussion. However, these two concepts provide a valuable tool for SH&E professionals. Indeed, each individual who explores these concepts will find specific subtleties unique to his/her case and, therefore, may require a slight shift in approach for applying these tools. Nevertheless, these methods (as well as other approaches) need to be considered so that SH&E professionals may present sound logic for the purpose of protecting personnel. ■

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