Receptor Height: 1.5 m in Dispersion Modeling

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Abstract

EPIcode (chemicals) and HOTSPOT (radionuclides), approved codes in DOE-HQ Toolbox, recommends a receptor height (ht) of 1.5 m by default, which is typical for "chest ht and breathing zone" near the ground surface. However, MACCS2 and other codes use zero meter receptor ht, and yield a highly conservative value at short distances. A ground level receptor ht means that a receptor is lying on the ground, which is not the typical case at all. A conservative value is not necessarily realistic.

At LANL on February 22, 2011, during excavation in Enclosure #9 of a 1940s landfill known as TA-21, Material Disposal Area B (MDA-B), operators unearthed 34 jars (~20 lb) containing beryllium powder/dust. Some jars were broken and ~ 50% jars were uncovered and ~50% jars were covered, causing release of beryllium powder/dust in the trench. An Industrial Hygienist set up an air monitoring equipment on a table (1.3 m ht) ~10 m away from the source within the enclosure. Total airflow passed through was 271 liter in 2.5 hr (1.81 L/min) at atmospheric pressure. The analysis showed 0.44 ug/m^3 (4.4E-4 mg/m^3) inside Enclosure #9, which is very low concentration, and further strongly supports 1.5 m receptor ht to be used for modeling. Receptor ht is important at short distances (e.g., 300 m).

1.0 Incident Description

On February 22, 2011, MDA-B operators were excavating a trench (15 ft W x 15 ft deep) that is in the middle of Enclosure 9. At the dig-face, a significant quantity of beryllium (Be) was observed. Thirty four (34) glass (Mason) jars from ~30 inches (in.) below grade were excavated from the trench, and then placed in the sorting area. An unknown number of jars were broken in the trench so this material was mixed with the soil. About 50% jars were uncovered and 50% jars were covered [1]. As a priority, the project Industrial Hygienist removed a jar from the dig face, took to a nearby safe area, and took samples for evaluation.

1). One wipe sample was taken from the inside surface of this open container. The Lab analysis showed that the wipe sample contained 40 mg/100 cm^2 (standard size by NIOSH), which is interpreted as a combination of Be powder (i.e., small metal spheres) and dust (loose contamination in oxide form), and loose soil (i.e, dirt). Proportion of Be powder, Be dust, and dirt is unknown. It is believed that loose material is mainly from the soil (not from Be-dust) because of the ongoing excavation and remediation activities in the landfill area.

Figure 1 includes 2 photos showing the condition of Be and jars. In these photos, dust is un-noticeable in glass jars. Jars contain mainly powder/chips with blue color appearance due to blue film, shown in Figure 2.

Photo 1


Photo 2

Figure 1. Photos of Beryllium in Jars in MDA-B Enclosure #9.

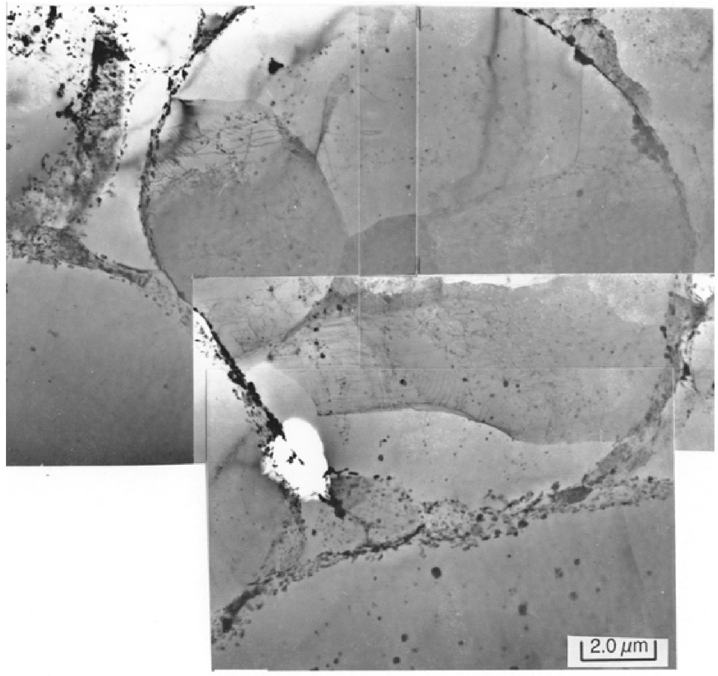

Figure 2. Tight Oxide Layer is "Blue Film"

Be has a strong affinity for oxygen to form oxide, oxidation ($2Be + O_2 \rightarrow 2BeO$). This oxide layer, called "blue film", is a thin (a few microns; 1.2% to 8.1% of the total weight), tight coating on the Be metal. It serves as a protective layer (vapor-diffusion barrier) that is continuous, non-porous and tightly-adherent [2].

2). A bulk sample was taken from inside the jar. Analysis shows that it is 97.2% beryllium metal shaving/chip (2mm) and with lead and nickel comprising the remainder.

3). Within about an hour (30 -45 min) of the incident, an Industrial Hygienist set up an air sampling equipment on a table (1.3 m height) at about 10 m from the dig-face. NIOSH approved filter (MEC filter) was used for measuring Be. Total airflow passed through was 271 liter in 2.5 hr (150 min), which is 1.81 L/min. The set up of monitoring equipment and measurement was unmitigated inside Enclosure # 9. Analysis showed 0.44 ug/m^3 (4.4E-4 mg/m^3) inside Enclosure #9, which is very low concentration . The Enclosure #9 air was exhausted to the environment through HEPA filtered ventilation [1,3].

4). From the appearance, Be metal chips look light and flaky in the glass jars. Weight information is not available. Operations personnel estimated that about 20 lb, in 34 jars, was uncovered, so 20 lb is used as estimate bounding amount to revaluate MDAB's chemical hazard categorization (CHC) [4]. It seems that spill or release came mostly from some broken jars and about 50% uncovered jars or bottles (see Figure 1, Photo 1), 10 lb is used for calculation by EPIcode to assess the results using 0 m vs. 1.5 m receptor height.

2.0 Enclosure # 9 Description

The enclosure is a like a dome with dimension of 296 ft long x 75 ft wide x 32 ft height (volume 7.10E+5 ft^3). Number of air exchange in the enclosure is 4.5 air/hr [1,3]. There was no negative pressure in the enclosure, indicating the atmosphere in the enclosure is the same as outside the enclosure (normal atmospheric pressure 11.17 psig at LANL). There are 8 exhaust systems (1 fan with 4 one ft diameter filters) are installed along the long wall of the enclosure, and supply air grills are located on the opposite wall to force airflow towards the exhaust filters.

Air flow through a HEPA filter is 1,500 cfm and air flow through an exhaust system (4 HEPA filters) is 6,000 cfm, and there are 8 exhaust systems, and thus 48,000 cfm in the enclosure. The air flow perpendicular to the exhaust fan/system is through a cross-sectional area of 276 ft x 32 ft = 8,832 ft^2. The velocity of airflow is then 48,000 cfm/8,832 ft^2 = 5.4 ft/min or 0.03 m/sec, which is a very low velocity. After a few weeks, air monitoring samples were rerun for beryllium level in the enclosure, prior to initiation of excavation activity, the concentration was essentially background level ($<0.03\ \mu g/m^3$) and below LANL action level.

3.0 Beryllium Concentration Calculations by EPIcode

The project Industrial Hygienist set up the air monitoring equipment after 30-45 min after the release, therefore, it is assumed that most of the puff release during the breaking of some jars was exhausted from the enclosure due to the 4.5 air changes per hour (2-3 changes). Thus, the steady release from airflow suspension of exposed Be was monitored during 2.5 hr (150 min) sampling at about 10 m distance at 1.3 m height. Two approaches are used to calculate source term (ST), which are as follows.

a. Source term (ST) = MAR x ARF x RF x DR x LPF (DR and LPF are taken as unity)

   Since some jars were broken and about 50% of jars were uncovered, and the total weight was estimated about 20 lb, so 10 lb is assumed as MAR for the term release. Beryllium is solid (Photo 1) and the ARF is taken as 1E-3 and it is low energy event and RF is taken as 0.1, so the ARF x RF is 1E-4. This results in a Source Term of 0.454 g Be.

b. Aerodynamic Entrainment and Resuspension (ARR): According to DOE-HDBK-3010-94, Page 4-10 [5], ARR value is 4E-5/hr, RF as 1.0, for homogeneous bed of powder exposed to ambient conditions (normal process facility ventilation flow or less, or nominal atmospheric wind speed <2 m/s with gusts up to 20 m/s). Resuspension release of 4E-5/hr is equivalent to 1E-8/s. For 10 lb Be MAR, the rate is 1E-8/s x 10 lb x 454 g/lb = 4.54E-5 g/s. Air sampling was carried out for 2.5 hr, so the total weight is 4.54E-5 g/s x 60 s/min x 150 min = 0.41 g, which is ~ 10% less than 0.454 g. This is modeled as a continuous release with EPIcode, to compare the results with term release.

Calculations are performed using EPIcode chemical dispersion model, which is an approved computer codes in DOE Toolbox [6]. EPICode's window version (7.0) is used here [7].

3.1 Parameters used for Modeling

Parameters for safety analysis are from EPIcode Manual [7] and DOE-EH-4.2.1.3-EPICode Guidance [8] and, which are as follows.

- Release type: Term release and continuous release are used for spill, which is modeled as a ground level release with no plume buoyancy and centerline plume concentration provides the maximum exposure to the receptor. Both releases are conservative.
- Stability Class: F, which is stable and a conservative estimate.
- Wind speed: 0.03m/s (calculated value in Section 2) at 2 m height is used.
- Release effective height: 0 meter, which is ground level release.
- Receptor height is typically 1.5 m, normally chest height and breathing zone, but 1.3 m table height is used, and zero height is also used for comparison.
- Release time (RT) and sampling time (ST) of 150 min each is used because the air monitoring equipment was run for 2.5 hrs.
- RF =1.0; ERPG/TEEL-3 (PAC-3) assumes total concentration exposure to a receptor.
- Terrain Standard: Open country which is more conservative than City terrain.
- Downwind X-meter: Plume centerline, Y-meter 0.

The results are summarized in Table 1. Distances taken for evaluation are 10 m, 20 m, 30 m, 40 m, 50 m, 60 m, 70 m, 80 m, 90 m, 100 m, 200 m, 400 m, 500 m and 700 m.

Table 1. Beryllium Concentrations at zero, 1.5 m and 1.3 m Height at Different Distances

	Spill (Term release) RT = 150 min; ST = 150 min			**Spill (Term Release) RT= 150 min; ST= 150 min**		**Spill (Continuous Release) RT= 150 min; ST= 150 min**		
MAR	10 lb	10 lb		10 lb	10 lb	4.54E-5 gm/sec		
ARFxRF	1E-4	1E-4		1E-4	1E-4	1.0	1.0	
Source Term (g)	0.454	0.454	**Case-1**	0.454	**Case-2**, 0.454	0.41	0.41*	**Case-3**
Receptor Ht	**0 m**	**1.5 m**	**0m/1.5m**	**1.3 m**	**0m/1.3m**	**0 m**	**1.3 m**	**0 m/1.3 m**
Concentration	mg/m^3	mg/m^3	**Ratio**	mg/m^3	**Ratio**	mg/m^3	mg/m^3	**Ratio**
10 m	4.9	3.1E-19	1.6E+19	1.9E-14	2.6E+14	4.4	1.7E-14	2.6E+14
20 m	1.2	1.8E-5	6.7E+4	**2.9E-4**	4.1E+3	1.1	**2.6E-4**	4.2E+3
30 m	0.55	3.8E-3	144	0.013	42	0.49	0.012	41
40 m	0.31	0.019	16	0.037	8.4	0.28	0.034	8.2
50 m	0.20	0.032	6.2	0.051	3.9	0.18	0.046	3.9
60 m	**0.14**	**0.040**	**3.5**	**0.053**	**2.6**	**0.12**	**0.048**	**2.5**
70 m	**0.10**	**0.038**	**2.5**	**0.050**	**2.0**	**0.092**	**0.045**	**2.0**
80 m	0.078	0.035	2.0	0.046	1.7	0.070	0.041	1.7
90 m	0.062	0.032	1.8	0.040	1.5	0.056	0.036	1.5
100 m	0.050	0.030	1.6	0.035	1.4	0.045	0.032	1.4
200 m	0.013	0.012	1.08	0.012	1.08	0.012	0.011	1.09
300 m	6.0E-3	5.6E-3	1.07	5.7E-3	1.05	5.4E-3	5.2E-3	1.04
400 m	3.5E-3	3.4E-3	1.03	3.4E-3	1.03	3.1E-3	3.0E-3	1.03
500 m	2.3E-3	2.2E-3	1.04	2.3E-3	1.00	2.1E-3	2.0E-3	1.05
700 m	1.2E-3	1.2E-3	1.00	1.2E-3	1.00	1.1E-3	1.1E-3	1.00
ERPG-3 mg/m^3)	**0.10**	**0.10**		**0.10**		**0.10**	**0.10**	
ERPG-2 mg/m^3)	0.025	0.025		0.025		0.025	0.025	

*ST for continuous release is 0.41 g, 10% lower than 0.454 g for term release. If adjusted, 2.6E-4 becomes 2.9E-4, thus both approaches yield the same value 2.9E-4 mg/m3 or 0.29 µg/m^3, which agrees well with the measured value of 0.44 µg/m^3.

4.0 Discussion of Results

Ratios of 0 m/1.5 m receptor height (ht) and 0 m/1.3 m ht are also shown in Table 1 for comparison. It is to note that ratios at 10 m are extremely high, which is unreliable and probably due to the high uncertainty in dispersion coefficients, and is not considered here. Only 20 m and onward distances are considered for discussion. The value at 20 m is considered for 10 m as the shortest distance. The ST 0.454 g (case-2) is 10% higher than ARR Case-3, ST 0.41 g and yield Be concentrations 2.9E-4 mg/m^3 and 2.6E-4 mg/m^3 within 10%. If case-3 ST is adjusted upward by 10%, then both are the same as 0.29 µg/m^3. Two approaches yield identical results and they are in excellent agreement by 50% with the air monitoring Be result of 0.44 µg/m^3, considering uncertainty in the dispersion coefficients and other parameters. This places confidence in the modeling calculations and further supports the concept that the receptor height parameter is very important consideration at short distances in modeling. Using 0 m ht results in about 3 orders of magnitude higher compared to the air monitoring sampling result at 1.3 m ht.

4.1 Sensitivity of 1.5 m Vs 1.3 m ht, wind speed, and RT and ST: For comparison, ratio of 0 m/1.5 m (case-1) is 6.7E+4, while the ratio of 0 m/1.3 m (case-2) is 4.1E+3. Case 1 value is 16 times higher than case-2, suggesting that the concentration or ratio is very sensitive to the receptor height (1.5 m vs. 1.3 m) Small difference in receptor height shows large variation in concentrations. Likewise, the ratio at 30 m is 144 for case-1 and 42 for case-2. This trend continues up to 300 m. Beyond 300 m, differences are small about 5%. Beyond 300 m, receptor height is not that important. However, receptor ht is important at short distances.

Wind speed used is 0.03 m/sec. If higher wind speed is used (e.g., 0.1 m/sec, 0. 5 m/sec), the values at 20 m decrease linearly by the ratio of 0.03 m/s to wind speed, indicating the model is sensitive to wind speed. The RT and ST used are 150 min each in term release. If RT and ST are changed to short duration say 15 min each, the results remain the same. This is because the term release is modeled as puff release, meaning whatever is released from the source, same amount is received by the receptor (RT=ST). If the RT and ST are much longer in duration (e.g., 150 min), term release model uses the plume equation, whereas, continuous release is always modeled as plumes. This explains why the term release with longer RT/ST yields identical results with continuous release.

Emergency Preparedness or management personnel are interested in or concentrations or doses at 30 m (Alert) and 100 m (SAE) for planning protective actions. In Safety Basis, DOE sites use 100 m for facility hazard categorization in nuclear or non-nuclear areas. At 100 m, zero ht yields concentrations 60% higher than with 1.5 m ht, which shows a much less effect than at shorter distances. However, by using 1.5 m receptor ht, one can increase threshold quantities (TQs) by 60%, which can help significantly in the facility chemical hazard categorization (CHC) and nuclear safety analysis for the selection of controls (SSCs) to mitigate consequences.

The EPIcode term release plot for 0 m ht is shown in Figure 1 and plot for 1.3 m receptor ht is shown in Figure 2. With 1.5 or 1.3 m receptor ht, the initial plume rises to peak plume concentration at 60-70 m (flat), and the value at 30 m may have significant uncertainty. The highest value at 60-70m (~65 m), which is about 10 times higher than at 30 m, and can be taken for the 30 m. This value at 60 m is about one order of magnitude lower as compared to the value listed at 0 m for the term release, which is still conservative and close to the realistic observed value for 30 m value.

Zero Receptor ht

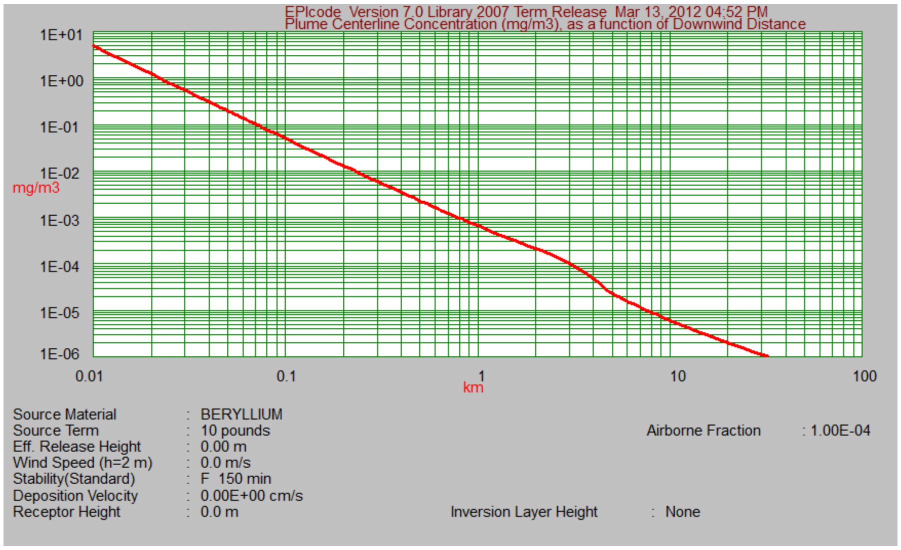

Figure 1. plot of Be Concentration Vs. Distance, Zero Receptor Ht (wind speed 0.03m/sec)

1.3 m Receptor ht

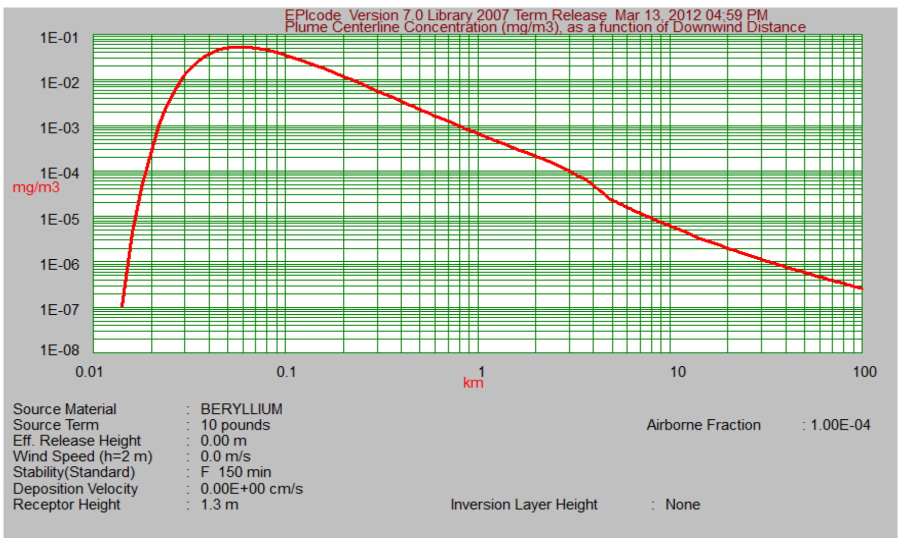

Figure 1. plot of Be Concentration Vs. Distance, 1.3 m Receptor Ht (wind speed 0.03m/sec)

5.0 Conclusions

The experimental measurement of Be by an air monitoring equipment at short distance from the spill or release is in excellent agreement with the value calculated by EPIcode modeling with receptor ht of 1.3 m. This further strongly supports 1.5 m receptor ht (chest ht and breathing zone) modeling at short distances. The values calculated at 1.5 m ht are reliable and much more realistic than values at 0 m ht, which over-estimates the concentration by several orders of magnitude as compared to the air monitoring result.

Cost Benefits: With zero receptor ht, the concentrations are overestimates at 100 m by 60% (Table-1) as compared to 1.5 m ht, which reduces the TQs for facility CHC. Further, for chemical safety analysis, consequences will be also an overestimate at 100 m with zero receptor ht for collocated workers, which will require controls (ML1) and involves significant costs that become cumulative over time. Likewise, for nuclear safety analysis there can be significant costs savings for the selection of controls (SSCs) to mitigate consequences for the workers at 100 m by using 1.5 m ht instead of zero receptor ht. Overall, the use of 1.5 m receptor ht is highly beneficial for CHC, FSA (chemical) and DSA (nuclear) facilities.

9.0 References

1. March 2nd , 2011 e-mail to Gary A. Exner: Bob Edger (IH) gave the results of 3 samples taken on 2/22/11. 1). Analysis of one swipe sample taken from a mason jar showed that it contained 40 mg/100 cm^2, which is interpreted as due to powder and dust (lose contamination in oxide form); 2). A bulk sample analysis showed that it was 97.2% Be shaving; 3). An Air sample was taken in ~ an hr of the incident using 271 L for 2.5 hr, and the monitoring equipment placed on a table (1.3 m ht), 10 m from the dig face, and analysis showed 4.4E-4 mg/m^3 or 0.44 μg/m^3. E-mail from Lee, Michael W to Grindstaff, Betsey J, on 9/13/11 stated that 34 small glass jar were uncovered. Per Jeff Erikson on 7/18/11, some jars were broken and ~50% jars were uncovered and ~50% were covered.
2. Jofu Mishima, Terry L. Foppe, and J.C. Laul, "Proposed Beryllium Metal Bounding Airborne Release Fractions (ARFs)/Rates (ARRs) and Respirable Fractions (RFs) for DOE Facility Accident Analysis", LA-UR-07-5556, *Chemical Health and Safety Journal*, Vol 14, July/August, 26-45, 2008.
3. Jeff Erickson, MDA-B Beryllium Sample Plan, TA-21-MDAB-Plan-00029, Rev. 1, May 12, 2011.
4. J.C. Laul and Terry Foppe, "Minimum Beryllium TQ (metal or oxide) for a Low Chemical Hazard categorization at TA-21 MDA-B", Submitted to SAWG meeting, May 5-10, 2012, Santa Fe, NM.
5. DOE-HDBK-3010-94, *Airborne Release Fractions/Rates and Respirable Fractions for Non-reactor Nuclear Facilities*, U.S. Department of Energy, Washington, D.C., December 1994.
6. DOE Safety Analysis Toolbox Central Registry – http://www.hss.energy.gov/csa/csp/sqa/centralregistry.htm
7. EPIcode Version 7.0 (2008); Manual is included in the CD.
8. DOE-EH-4.2.1.3-EPIcode Code Guidance, "EPIcode Computer Code Application Guidance for Documented Safety Analysis", U.S. Department of Energy, Washington, D.C., June 2004.