October 23, 2012

EVALUATION OF INADVERTANT INGESTION OF RADIONUCLIDES DCAS' RESPONSE TO SC&A'S EVALAUTION OF TIB-009

Background

The current approach to estimating ingestion intakes for workers without bioassay monitoring data is described in DCAS Technical Information Bulletin 009 (OCAS-TIB-009). This TIB, which has been used to estimate ingestion intakes during both the operational and residual contamination periods, relies on ambient air concentration measurements to estimate the amount of daily ingestion in the workplace. Specifically, TIB-009 estimated that the total daily ingestion is equal to 20% of the activity contained in one cubic meter or air[1]. The model in TIB-009 was originally reviewed by SC&A in June of 2006 (SC&A 2006). In their review, SC&A commented that the model was likely to produce intakes that are too low and unrealistic. The basis for this opinion was provided in the following findings that were included in their evaluation report.

- Surface contamination levels are likely to be orders of magnitude higher than predicted by the settling velocity of airborne contaminants assumed at 5 microns. For example, at uranium rolling mills, airborne particulates are likely to represent a distribution of particles that range from a few microns to large/visible particles. For larger particles, settling velocities increase dramatically and while large particles limit internalization by inhalation, there are no limitations for their ingestion.
- Surface contamination is likely to build up over time that may extend to weeks/months or longer before reaching equilibrium. NIOSH's assumption that this equilibrium is reached in a 24-hour period is without scientific basis and highly unconservative.
- For select processes, surface contamination may not be the result of settling, but may include liquid spills, or result from milling, grinding, cutting, welding, etc.
- The modeled transfer of surface contaminations to the mouth that assumes a 10% transfer from the surface area of one hand during a full workday appears unrealistic. In a hot/dusty work environment, a "radiologically uninformed/untrained" worker is likely to contact/wipe his/her face with both hands repeatedly over the course of a full workday.
- Ingestion may involve other modes such as direct deposition on lips, smoking of cigarettes, etc.

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[1] Inadvertent ingestion in TIB-009 does not apply to the intake of radioactive material that is inhaled and subsequently removed from the lungs to the gastrointestinal tract. This mode of ingestion is included in the IRCP's respiratory tract model.

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NIOSH has reviewed the above findings and concurs that the parameters used in the TIB-009 model are based on assumptions that have not been empirically demonstrated to be valid. The main concerns expressed in SC&A's findings center on two issues: 1) the possible lack of an association between measured air concentrations in the workplace and surface contamination, and 2) the modeled transfer of the surface contamination to the GI tract through inadvertent ingestion.

<u>Characterization of the relationship between air and surface contamination levels</u>

To evaluate the relationship between air contamination and surface contamination levels, NIOSH reviewed the available air and surface contamination measurement at Simonds Saw and Steel and Bethlehem Steel. At Simonds Saw Steel these measurements were taken during a uranium rolling campaign on 10/27/48 and were direct measurements made with a portable instrument called a Zeuto[2]. This type of instrument has an active surface area that is 3 inches by 4 inches or approximately 75 cm^2. The Bethlehem Steel data, available for a rolling on 9/14/1952, were obtained by smears wiped over a 100 cm^2 area. As such, they represent only the removable portion of the contamination. Each rolling stand at both Bethlehem Steel and Simonds Saw were evaluated along with the shear at Bethlehem Steel. Stand #6 at Bethlehem Steel was not evaluated because the surface smear indicated no detectable activity. Where more than one sample was taken, the results were averaged.

Subsequent to the analysis of the Bethlehem Steel and Simonds Saw and Steel data, NIOSH found paired surface contamination and air concentration data at two additional facilities. The first of these were collected at Superior Steel during a test rolling on 5/13/53. The air data was collected at one of the finishing rollers while the smear was collected 20 feet east of the roller.

The second set of data was found at the Vitro Manufacturing facility in Canonsburg, Pennsylvania. Between 8/18 and 8/20 of 1953, a series of air sample and contamination smears were collected by representatives of the Health and Safety Laboratory (HASL). In all, approximately 240 air samples and 150 contamination smears were collected at various locations within the plant. These data were entered into an EXCEL spreadsheet and the distributions of the data were characterized. Because both data sets were found to be log-normally distributed, the geometric mean and standard deviation was calculated for each set.

Table 1 provides the air and surface contamination measurements for the facilities described above.

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[2] As a direct measurement device, the Zeuto quantifies total activity that would include both fixed and loose contamination. As loose contamination is the only type of material that contributes to ingestion, the use of this value would provide an overestimate of the source term available for the ingestion pathway.

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Table 1 – Air and Surface Contamination Values

Air sample reference	Air concentration (dpm/m^3)	Surf. Contamination location	Surf. Contamination value ($dpm/100\ cm^2$)
Simonds Saw Data			
L709	49000		
L710	75000	east roller 1	50000
L711	22400	west roller 1	35000
Average	48800	Average	42500
L718	14800		
L719	23800		
L720	27900		
L721	943		
L722	836		
L723	418	west roller 2	15000
average	11449.5	Average	15000
Bethlehem Steel Data			
Q921	2076		
Q922	2973	Shear	679
Q923	1080	Shear	404
Average	2043	Average	541.5
Q903	3		
Q905	10	Stand 1	2
Average	6.5	Average	2
Q906	10		
Q908	12	Stand 2	9
Average	11	Average	9
Q909	18		
Q911	14	Stand 3	6
Average	16	Average	6
Q912	13		
Q913	10		
Q920	6	Stand 4	5
Average	9.7	Average	5
Q914	12		
Q915	3		
Q919	12	Stand 5	9
Average	9	Average	9
Superior Steel Data			
SRDB 6898 (pages 4-6)	7600	Finish roll #5	1140
Vitro Manufacturing			
SRDB #10448[3] and 10450	GM = 25.3	Plant-wide	GM = 68.0

[3] Samples are from pages 1-18 of SRDB #10448. Control samples and blanks and several samples without an indicated flow-rate were omitted from analysis.

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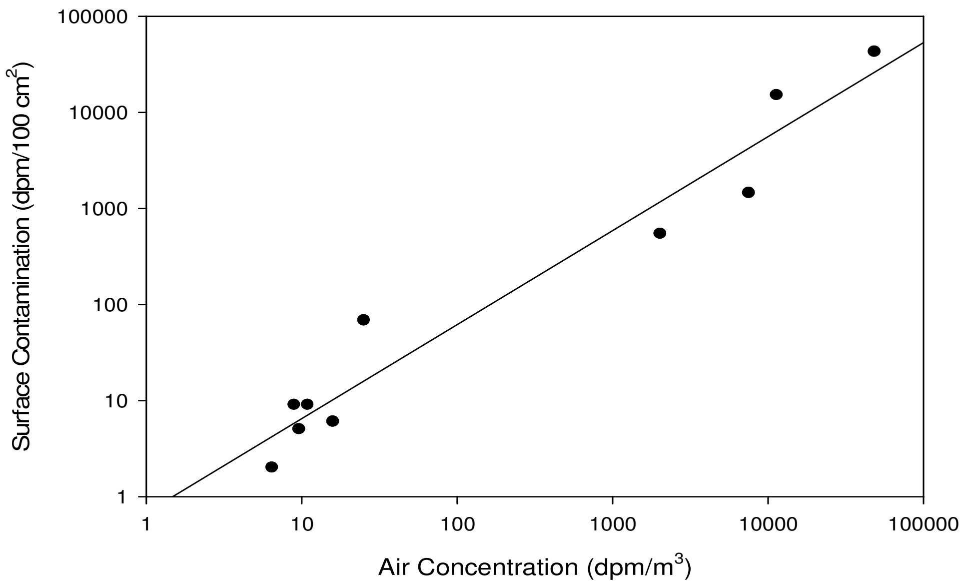
The values for each pair of air concentration and surface contamination values are plotted in Figure 1. The clear trend can be seen in Figure 1 that empirically demonstrates the measured surface contamination levels are proportional to air contamination. It is also worthy of note that this relationship is internally consistent at Simonds Sam and Steel and Bethlehem Steel. That is, high airborne activity is predictive of high surface contamination levels and vice versa. This means that if any large particle surface contamination that does not add to the air concentrations exists, the fraction of surface contamination represented by this is consistent across locations and sites and concentrations.

Figure 1 – Graph of observed air concentration and surface contamination levels



A linear regression analysis was performed on the dataset plotted in Figure 1 and the following results were obtained[4]:

$$S_c = 116.7 * A_m$$
$$r^2 = 0.96$$

where S_c = the estimated level of surface contamination in dpm/m^2, and
A_m = the measured air concentration in dpm/ m^3.

Given that there is a relationship between air concentration and surface contamination level, it should be possible to use air concentration values to estimate ingestion intakes.

[4] Since surface concentration should be zero in the presence of no airborne activity, the data were analyzed with the intercept set through the origin.

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The only other factor required to establish this relationship is the daily ingestion rate for loose surface contamination.

Evaluation of the daily ingestion rate

The model put forth in TIB-009 assumes that there are two modes of ingestion – one from the ingestion of material that had settled onto a drinking container and one from the ingestion of material that was transferred to the hand and subsequently to the mouth. While the scenario modeled in TIB-009 seems plausible to NIOSH, it is acknowledged that neither of the assumptions used in the model are based on peer reviewed studies of the work habits of individuals.

The NRC computer program RESRAD-BUILD (NRC 2002) does, however, contain an ingestion parameter that is based on an extensive review and analysis of the literature surrounding this intake pathway. In this model, ingestion of radionuclide contamination in the workplace is directly related to the amount of loose surface contamination present. If the amount of loose surface contamination per unit area is known, a worker's hourly ingestion rate can be calculated as follows:

$$I_h = C_m * GO$$

where I_h = the hourly ingestion rate in dpm/h;

C_m = the surface contamination measured in the workplace in dpm/m^2; and

GO = the effective transfer rate for ingestion of removable contamination in m^2/h.

The value for GO used in the RESRAD model is represented by a log-uniform distribution with values between $2.8x10^{-5}$ and $2.9x10^{-4}$ m^2/hr and a mean of $1.1x10^{-4}$ m^2/hr. Although the value for GO was originally considered a constant when it was developed in volume 1 of NUREG/CR-5512 (NRC 1992), it was subsequently updated to a log-normal distribution in Volume 3 (NRC 1999). In volume 3, there was an attempt to correlate ingestion intakes with soil ingestion studies that had recently been published. The mean ingestion rate for the adult studies corresponded to an ingestion of 50 mg/day which would correspond to a worker ingesting 100 cm^2 of contaminated surface per hour. This value was considered by the authors to be implausibly high and the use of soil ingestion study data to set the upper limit was abandoned. In the end, the average value of 1.1×10^{-4} m^2/hr (corresponding to an ingestion of about 0.5 mg/day) was considered to represent the average member of the screening group and was said to define the default value for GO. The corresponding ingestion rate for an 8 hour work day would be 8.8×10^{-4} m^2/d.

The difficulty of applying this parameter to the facilities covered under the Energy Employees Occupational Illness Compensation Program Act is that very few

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measurements of surface contamination exist in situations where ingestion levels must be estimated (i.e., those facilities where bioassay measurement data cannot be used to estimate total intake). This is especially true for Atomic Weapons Employer (AWE) facilities during the residual contamination period.

Tying together air concentration, surface contamination, and ingestion

Given that a relationship has been established between air concentration values and surface contamination levels, and a default value for daily ingestion has been identified, it is possible to evaluate workplace ingestion based solely on air concentration data. This can be expressed as follows:

$$I_d = 116.7 * A_m * GO$$
$$I_d = 0.103 * A_m \qquad (1)$$

where I_d = the daily ingestion of loose radioactive material in dpm/d,
A_m = the measured air concentration in the workplace in dpm/m^3, and
GO = the NUREG/CR-5512 default for ingestion in the workplace in m^2/d
= 8.8 x 10^{-4} m^2/d.

As discussed previously, TIB-009 guidance is to estimate daily ingestion intake using the following relationship:

$$I_d = 0.2 * A_m \qquad (2)$$

where I_d = the daily ingestion rate in dpm/day; and

A_m = the air concentration measured in the workplace in dpm/m^3.

Discussion

It can be seen that the intakes based on empirical data and mean value for GO (equation 1) would predict ingestion intakes that are almost exactly half of that of the approach based on TIB-009 (equation 2). Thus, even though the parameters and assumptions used in TIB-009 were somewhat simplistic, the model nonetheless produces estimates of ingestion that are in reasonable agreement with the NUREG predictions. It should also be considered that the 20% multiplier used in TIB-009 includes an ingestion source term for a contaminated beverage or food item. This type of ingestion was not considered in the development of GO in the NUREG. Given the uncertainty inherent in the values discussed above, it is not unreasonable for NIOSH to continue using the TIB-009 approach for estimating intakes.

It should also be mentioned that the ingestion exposure pathway results in doses that are quite small compared to inhalation exposure. Under the TIB-009 approach, ingestion will always be a fraction of the inhalation exposure (i.e., 1 dpm/m^3 of air activity will

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result in the assignment of daily inhalation and ingestion exposures of 9.6 dpm and 0.2 dpm/day, respectively). In addition, for uranium intakes (for which TIB-009 is almost exclusively applied), the uptake across the gastrointestinal tract is low. This combination of factors results in the ingestion pathway contributing less than 0.6% to the dose for soft tissues under all solubility types[5]. The maximum contribution for ingestion would be, as expected, to organs of the gastrointestinal tract. For these organs, the highest contribution to a dose is 3.4% for lower large intestine when insoluble material (ICRP type S) is inhaled.

Application of TIB-009 during residual contamination periods

Based on a recent review of the approach adopted for estimating ingestion intakes at the Dupont Deepwater Works (DCAS-TBKS-0006), it has been discovered that TIB-009 has been improperly applied during the residual contamination period. For periods of time after the cessation of AEC activities, it is inappropriate to use a resuspension factor to estimate an air concentration and then multiply that value by 0.2 to calculate a daily ingestion intake. The reason for this is that the relationship between air concentration and surface activity in TIB-009 assumes an active source or process is generating the airborne activity. The airborne activity predicted using a resuspension factor of, for example 1 $x10^{-6}$/m, would grossly under represent the airborne activity that actually deposited the surface contamination. For TIB-009 to be applied during residual contamination periods, the air concentration on the first day of the residual contamination period should be assumed to be equal to that which was present during the end of operations. The ingestion calculated in this manner can then be decreased over time using the source depletion techniques described in TIB-0070.

A review of several TIBs has revealed that this error is not isolated to the Dupont Deepwater works. A comprehensive review of the estimation of ingestion during the residual contamination period will be conducted for all TIBs. As errors are discovered, the TIBs will be revised and a program evaluation report (PER) will be issued.

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[5] Assuming a chronic inhalation exposure over a one year period.

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